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August 1967

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(TITLE UNCLASSIFIED)

ADVANCED ROCKET ENGINE--STORABLE

PHASE I INTERIM FINAL REPORT

Part 3 of three parts

Appendixes

Prepared by

AEROJET-GENERAL CORPORATION

ADVANCED STORABLE ENGINE PROGRAM DIVISION

LIQUID ROCKET OPERATIONS

SACRAMENTO, CALIFORNIA

Prepared for

AIR FORCE ROCKET PROPULSION LABORATORY

RESEARCH AND TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

EDWARDS, CALIFORNIA

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AEROJET-GENERAL CORPORATION

A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

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Report 10830-F-1, Phase I

FOREWORD

This report reviews the technical accomplishments of the ARES Advanced Development Program, Contract AF 04(611)-10830, from 1 July 1965 through 27 January 1967. The work during this period was directed primarily toward demonstrating the feasibility of advanced components and subsystems considered critical to the integrated engine module design. Analysis, design, fabrication, and test activities are summarized.

All work was performanced by Liquid Rocket Operations of Aerojet-General Corporation for the Air Force Rocket Propulsion Laboratory at Edwards Air Force Base, California. Mr. R. Beichel is the Aerojet Program Manager, and Mr. C. W. Hawk is the Air Force Program Manager.

This report has been divided irto three separate parts for ease of handling.

This technical report has been reviewed and is approved.

C. W. Hawk
USAF Program Manager

UNCLASSIFIED ABSTRACT

(U) This report summarizes the Phase I work on Contract AF 04(611)-10830 through 27 January 1967.

(U) The objective of the program was to demonstrate in two phases the engineering practicality and performance characteristics of a high chamber pressure, staged combustion engine module. Before the complete engine can be assembled and tested in Phase II, a Phase I effort must demonstrate the feasibility of several features considered critical to the engine design.

(U) The Phase I program to date has accomplished the following:

a. Established master layouts for both an advanced engine design and for a relatively more conservative back-up version of the engine.

b. Established a master layout for a very large thrust propulsion system utilizing 20 engine modules in a cluster, with all modules exhausting into a single large forced deflection nozzle.

c. Detail designed all the engine components.

d. Demonstrated a successful primary injector and combustion chamber for production of the turbine drive gas.

e. Demonstrated transpiration cooled chambers that can apparently meet contractual performance goals when a suitable secondary injector is evolved.

f. Demonstrated the feasibility of lubricating turbopump bearings with the storable propellants used in the engine.

UNCLASSIFIED ABSTRACT (cont.)

g. Demonstrated pump wear ring designs that permit operation at very close clearance with little or no explosion hazard from pump rub.

h. Demonstrated the suitability of high pressure multiple purpose housings for the turbopump and primary combustion chamber assembly.

i. Developed and demonstrated satisfactory propellant flow control components for the full-scale engine.

j. Completed several supporting studies that provide additional design criteria in such areas as nozzle Aerodynamics, low frequency stability, fluid flow characteristic of propellant and turbine drive-gas passage, and design changes required for conversion to advanced storable propellants.

(U) Remaining Phase I technical goals are conclusion of 60 sec of simulated engine operation with the hydrostatic combustion seal, and three 20-sec firings of a cooled combustion chamber at contractually required specific impulse or higher. The current effort to achieve a high performance, streak free secondary injector must be completed before the cooled thrust chamber demonstration can take place.

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FIGURE LIST

FIGURE LIST (cont.)

0.0 CHANGE NOTICE

0.1 DESCRIPTION

The latest change notice will be filed in this section immediately after this page.

27 August 1965

Report 10830-F-1, Phase I, Appendix I

ENGINE HANDBOOK
CHANGE NOTICE

Revision Number 18
10 March 1967

Remove	Replace with
Engine Handbook, including Revision No. 17, dated 23 November 1966	New issue of Engine Handbook, Revision No. 18, dated 10 March 1967

NOTE:

The Engine Handbook, Revision No. 18, dated 10 March 1967, is a complete reissue. It replaces and supersedes in entirety all previous issues and revisions, which should be destroyed.

1.0 ENGINE HANDBOOK

1.1 Purpose

The Engine Handbook is a contractual item as specified by: Abstract Attachment 1, Exhibit B, of the Work Statement for this contract, and by ammendment(s) thereto.

The main requirements are:

(a) The Engine Handbook shall consist of a looseleaf binder containing pertinent design data, tables of performance data, reduced drawings of major items such as turbopumps, injectors, thrust chambers, etc.

(b) The Engine Handbook shall be submitted initially on 1 August 1965.

(c) The Engine Handbook updating requirement was changed to: "Effective 11 January 1966, the Engineering Handbook shall be updated monthly and shall be due the 25th of the month following the reporting period."

(d) Additional data shall be supplied separately as follows: "The Contractor shall provide raw test data, photos, drawings, sketches, informal notes, and other pertinent program data on a weekly or as necessary basis for one copy of the Engineering Handbook. The Contractor shall submit said data in a timely manner to the Air Force Project Engineer for insertion in his Engineering Handbook." However, this handbook does not include the added test data, etc, supplied to the Air Force Project Engineer.

Within Aerojet this handbook is used as a working document by cognizant personnel in day-to-day work.

2.0 ADVANCED STORABLE ENGINE

2.1 DESCRIPTION

(u) The Advanced Storable Engine is a high chamber pressure, staged-combustion cycle engine, utilizing storable liquid propellants (N_2O_4/AeroZINE 50)*, and has a nominal thrust of 100,000 lb. It is designed for improved performance, weight, and cost, and adaptability to applications where clustering of engines is required. The engine is pump-fed with a single-shaft turbopump assembly. The thrust chamber is regeneratively cooled with the oxidizer; the oxidizer flow then is used in an oxidizer-rich generator to drive the turbine. All the turbine exhaust gas enters the thrust chamber where it is burned with the fuel. The staged-combustion cycle is shown in Figure I-2.1-1.

(u) The layout drawing of the engine module subassembly (without boost pumps) is shown in Figure I-2.1-2, with an external dimensioned view in Figure I-2.1-3.

(u) An external view of the module assembly including boost pumps and lines arranged for static test is shown in Figure I-2.1-4. This figure also shows the module interface with facility-provided controls, purges and drains.

An internal view of the module assembly including boost pumps and lines is shown in Figure I-2.1-5. The drawing reproduced in this figure updates the contractual work statement reference drawing 1120394.

2.2 APPLICATIONS

(u) The main application under consideration is a 20-module propulsion system as stated in paragraph 2.1.2.1 of Exhibit "A," of Contract AF 04(611)-10830. In addition, consideration will be given to all vehicles, and stages thereof, to assure a universal module design. A 20-module installation is shown in Figure I-2.2-1.

2.3 ENGINE MODULE SPECIFICATION

2.3.1 External Performance Parameters

(C) The performance of the engine module is specified in paragraph 2.2.5.2.1 of Exhibit A and paragraph III.A.1 of Exhibit C of Contract AF 04(611)-10830, and is summarized as follows:

*AeroZINE 50 -- Aerojet-General Corporation tradename for a .50 hydrazine-.50 UDMH.

2.3, Engine Module Specification (cont.)

(C) Operating Conditions:

Thrust:	100,000 lb ± 5,000 lb
Chamber pressure:	2,800 psia ± 140 psia (5%)
Area Ratio:	20:1 (80% optimum bell contour)
Propellants	N_2O_4/.5N_2H_4-.5 UDMH

Performance:	Target	Minimum	Maximum
Specific impulse:	285 sec	283 sec	292 sec

Net positive suction head, oxidizer 30 ft

Net positive suction head, fuel 43 ft

2.3.2 Interfaces

(u) The module interface conditions and module envelope constraints will initially be based on the 20-module propulsion system specified in paragraph 2.1.2.1 of Exhibit "A," Contract AF 04(611)-10830. The 20-module propulsion system and other applications are presented in paragraph 2.2 of this handbook. The module interface drawings are listed in Section 13.

2.3.3 Weight

(u) The specified maximum engine module weight is 850 lb. The specified target weight is 675 lb. The module weight will be in conformance with Aerojet-General Drawing 1120394 and revisions thereto (see Figure I-2.1-5), including all parts listed thereon with the exception of propellant suction lines, instrumentation, harnesses, and connectors.

2.4 ENGINE OPERATION REQUIREMENTS

2.4.1 General

(u) This section of the Handbook describes transient operations during startup, acceleration, and shutdown. Figures I-2.4.1-1 through I-2.4.1-7 show the predicted module control characteristics in the form of steady state operating maps. These maps were developed on the steady state mathematical model by variation of both fuel valves through their full operating ranges. Valve position is expressed in K_w, i.e. flow coefficient.

2.4.2 Start

The engine will be capable of "tank head" start. That is, no auxiliary turbine power source will be required. Upon opening of the suction valves and fuel control valves in the proper sequence, the engine will start.

2.4.3 Acceleration

The predicted valve sequence and major transient parameters for a normal tank head start and acceleration are plotted in Figure I-2.4.3-1.

As shown in the figure, the oxidizer suction valve is opened initially, followed immediately by the fuel suction valve, allowing the propellants to flow through the pumps. The primary fuel control valve then is opened to its initial step position (6% open), with sufficient delay to insure filling of the primary injector oxidizer manifold before filling of the fuel manifold. Ignition occurs in the primary combustor at the time of filling the fuel manifold, at which point the secondary fuel control valve is opened, allowing secondary combustor ignition. The primary fuel control valve is then opened from its step position to its full operating position, and the engine completes its acceleration to full thrust operation.

2.4.4 Shutdown

Shutdown of the engine will be accomplished by closing in sequence the primary fuel control valve, the secondary fuel control valve, the fuel suction valve, and the oxidizer suction valve. The predicted valve sequence and major transient parameters for a normal shutdown are plotted in Figure I-2.4.4-1.

2.5 ENVIRONMENTAL REQUIREMENTS

2.5.1 Temperature

The engine module assembly will be designed for propellant and engine temperatures at startup from 35°F to 85°F.

2.5.2 Altitude

The components and module will be tested under sea-level conditions, but will be designed for an ICBM flight profile. The engine will be adaptable to any stage of a single- or multiple-stage vehicle.

2.6 MODULE DESIGN PRESSURE AND FLOW SCHEDULE

The engine design pressure and flow schedules are shown in Tables I-2.6-1 and I-2.6-2.

2.7 MODULE PERFORMANCE

The module predicted operating parameters for the target performance point are presented in Table I-2.7-1. Corresponding flows are shown in the module flow schematic in Figure I-2.6-1.

The predicted effects of film cooling on performance characteristics are shown in Figure I-2.2-1. The predicted effects of turbopump component efficiency deviations on engine performance and on turbine inlet temperature are shown in Figures I-2.7-2 and I-2.7-3, respectively. The predicted effects of turbine nozzle throat area deviations on turbine inlet temperature, pressure ratio, shaft speed, and oxidizer pump discharge pressure are shown in Figure I-2.7-4.

The target operating point within the work statement demonstration limits for the engine module is shown in Figures I-2.7-5 and I-2.7-6. Figure I-2.7-5 shows the turbine inlet temperature, oxidizer pump discharge pressure, and shaft speed that would occur during steady state operation throughout the work statement limits of thrust and chamber pressure, with a nominal thrust chamber throat area as well as with an assumed ± 5% variation in throat area. The data are for constant target specific impulse. Figure I-2.7-6 shows the oxidizer pump head, flow, and shaft speed that would occur at these same variations of thrust, chamber pressure and throat area. In addition, this figure shows the effect of variation of specific impulse from the target value to the work statement limits.

Table I-2.6-1

ARES MODULE AND COMPONENT DESIGN OPERATING PRESSURE SCHEDULE (TARGET PERFORMANCE) ADVANCED TPA CONFIGURATION (u)

This pressure schedule is based on (1) allocated flow passage K_W values per Table I-2.6-2, (2) minimum allocated turbopump efficiencies and (3) target module performance. These pressure values define target operating requirements for Phase I design purposes, and will remain in effect unless an increase in module operating pressures becomes incompatible with existing design margins of safety.

Pressure, psia (Total Press. Unless Otherwise Indicated)	Liquid Oxidizer	Hot Gas	Liquid Fuel
Boost Pump Inlet	36.6* 75**		19.5* 75**
Boost Pump Discharge	310 340		170 225
Main Pump Inlet	255 295		135 190
Main Pump Discharge	6025		3750
Main Pump Outlet Port to Hyd. Turbine	5855		3630
Boost Pump Turbine Inlet Port	5600		3440
2nd Stage Fuel Pump Inlet			3400
2nd Stage Fuel Pump Discharge			5765
Cooling Jacket Inlet	5900		
Film Cooling Manifold	5900		
Cooling Jacket Exit	5125		
PC Injector Inlet	5000		5100
PC Injector Face		4700	
Turbine Inlet		4575	
Turbine Exit (Blade), Static		3050	
Turbine Exit (Blade), Total		3100	
SC Injector Inlet		3010	3200
SC Injector Face		2885	
SC Chamber (Pc)		2800	

*Corresponds to minimum NPSH per work statement
**Predicted maximum static test starting pressure

Table I-2.6-2

ARES MODULE FLOW PASSAGE DESIGN REQUIREMENTS (u)

1. Minimum Admittance Requirements

Pages 2 and 3 of this table define the minimum allocated admittance flow factor (maximum pressure drop) of each major passage or group of passages.

2. Flow Equalization Requirements

a. Oxidizer Pump

(1) Flow from the oxidizer pump diffuser shall be uniform in each diffuser passage within ±4% of the average value.
(2) Oxidizer flow from each housing port feeding the primary combustor injector shall be uniform within ±3% of the average value.
(3) Static pressures in the oxidizer equalization annulus at the exit of the pump housing discharge passages shall be uniform within ±40 psi of the nominal steady state value.
(4) Static pressures in the oxidizer equalization annulus at the inlet of the pump housing return passages shall be uniform within ±40 psi of the nominal steady state value.
(5) Oxidizer liquid flow velocity shall be 10 ft/sec or greater in the oxidizer pump housing passages where passage walls are in contact with hot gas flowing to and from the turbine.

b. Primary Combustor Injector

(1) Oxidizer flow from each primary combustor injector nozzle shall be uniform within ±4% of the average value. This flow equalization shall be accomplished with oxidizer flow entering the primary combustor injector from the oxidizer pump housing with housing flow distribution limits as specified in paragraph 2a (2) above.
(2) Fuel flow from each primary combustor injector nozzle shall be uniform within ±1% of the average value.

c. Turbine

Turbine drive gass flow from the primary combustor shall be uniform through each turbine nozzle within ±3% of the average value. Flow shall be uniform from the turbine nozzle I.D. to O.D. within ±5%.

d. Secondary Combustor Injector

(1) Hot gas flow to the secondary injector shall be uniform at the plane of fuel injection. Tolerance allocation will be defined in terms of flow zones where Zone A is the outer 50% of the annular area (from the injector outer diameter to 0.707 or the outer diameter) and Zone B is the inner 50% of the annular area (from the 0.707 diameter to the center of the injector).

(a) Gas flow in Zone A shall be uniform with variations not exceeding +5%, -0% of the average value of Zones A and B.
(b) Gas flow in Zone B shall be uniform with variations not exceeding +0%, -5% of the average value of Zones A and B.

(2) Fuel flow from each of the secondary combustor injector nozzles shall be uniform within ±1% of the average value.

24 October 1966

Table I-2.6-2

ARES MODULE FLOW PASSAGE DESIGN REQUIREMENTS (u)

	Flow Factor $K_W = \frac{\dot{W}}{\sqrt{\Delta P \times S.G.}}$		Example only Reference ΔP, Flow and Spec. Grav. (used to establish min.allocated K_W)		
Hydraulic Passages:	Minimum Allocated K_W	Predicted or Test Value	ΔP, psi	$\dot{W}$, lb/sec	S.G.
Oxid. Suction Line	34		51.5	291.8	1.433
Oxid. Suction Valve	120		4.1	291.8	1.433
Oxid. Outer Housing Passage (Pump to Cooling Jacket)	18.6		125	248.2	1.433
Oxid. Cooling Jacket	6.9		775	217.2	1.282
Oxid. Inner Housing Passage (Cooling Jacket to PC Injector)	17.2		125	217.2	1.282
Oxid P.C. Injector	10.9		300	213.3	1.282
Oxid. Pump Disch. to Hyd. Turb. Port	2.50		170	39	1.433
Oxid. Hyd. Turb. Line & Check Valve	2.30		200	39	1.433
Oxid. Hyd. Turb. Orif. (Nominal)	4.39		55	39	1.433
Fuel Suction Line	20.6		34.8	115.2	.9
Fuel Suction Valve	110		1.2	115.2	.9
Fuel S.C. Valve and Passage (valve full open)	7.01		146	80.3	.9
Fuel S.C. Manifold and Injector	4.16		415	80.3	.9
Fuel Stage 2 Suction Passage	-		350	23.8	.9
Fuel P.C. Valve and Passage (valve wide open)	1.19		271	18.6	.9
Fuel P.C. Line to Injector	2.77		50	18.6	.9
Fuel P.C. Injector	0.98		400	18.6	.9
Fuel Pump Disch. to Hyd. Turb. Port	1.54		120	16	.9
Fuel Hyd. Turb. Line & Check Valve	1.51		125	16	.9
Fuel Hyd. Turb. Orif. (Nominal)	2.09		65	16	.9

NOTES:
1. ΔP, flow, and specific gravity values are for example only. For latest predicted pressures and flows, see ARES Module Operating Point, Fig. I-2.7-1.
2. Pressure drop alone does not establish a firm requirement for a passage since pressure will vary with minor changes in flow, and to a lesser degree with density. Wherever practical, the K flow factor should be used in place of ΔP as design criteria, since the measured K of a given piece of hardware will not change with operating conditions.

24 Aug 1966

Table I-2.6-2 (Cont.)

Gas Passages:	Flow Factor $K_g = \frac{\dot{W}}{\sqrt{\Delta P \times S.G.}}$ Minimum Allocated K_g**	Predicted or Test Value	Example only Reference ΔP, Flow and Spec. Grav. (used to establish min. allocated K_g) ΔP, psi	$\dot{W}$, lb/sec	S.G.*
P.C. Injector Face to Turbine Inlet	2.02**		125	231.9	106*
Turbine Exit to S.C. Injector	3.01**		90	239.6	70.7*
S.C. Gas Injector	2.60**		125	239.6	68.2*
S.C. Injector Face to Plenum	P_{Inj}/P_c = 1.03		85	-	-

*Spec. grav. of gas = $\frac{\rho \text{ gas}}{\rho \text{ air}} = \frac{Ps/RTs \text{ (avg. gas)}}{.0808}$

**For gas passages, flow factor Kg is used instead of K_w, where effective K_g includes heat addition losses.

24 August 1966

Table I-2.7-1

ARES MODULE TARGET OPERATING POINT
ADVANCED TURBOPUMP CONFIGURATION (u)

The parameters in this table with the conditions noted below define Target Operating Point Number 5. This is a predicted target module/component operating point based on predicted component performance, and shall not be used as a design specification.

Assumptions, Target Operating Point No. 5	Reference	
1. Cycle Configuration: oxidizer and regeratively cooled secondary combustor	ARES Flow Schematic, Figure I-2.6-1, dated 10 March 1967	
2. Balanced for target performance	Paragraph 2.3.1	
3. Secondary combustor performance vs oxidizer film coolant flow	Figure I-2.7-1, dated 10 March 1967	
4. Turbopump predicted performance:	Figure	Date
Oxidizer Pump		
H vs Q	I-3.3.3-1	22 April 1966
Efficiency	I-3.3.3-1	"
Cavitation head loss	I-3.3.3-2	10 March 1967
Note: Design H was biased by factor of H/H_D = .969 to obtain module balance.		
Fuel Pump, 1st Stage		
H vs Q	I-3.3.3-1	22 April 1966
Efficiency	I-3.3.3-1	"
Cavitating head loss	I-3.3.3-2	10 March 1967
Fuel Pump, 2nd Stage		
H vs Q	I-3.4.3-1	22 April 1966
Efficiency	I-3.4.3-1	"
Turbine		
Torque Parameter	I-3.5.3-1	10 March 1967
Turbine Efficiency	I-3.5.3-2	"
Flow Parameter	I-3.5.3-3	
Note: Turbine predicted performance includes increase in efficiency, based on air flow test data.		

Table I-2.7-1 (cont.)

Assumptions, Target Operating Point No. 5	Reference Figure	Date
Boost Pumps		
H vs Q	I-4.1.3-1	24 May 1966
Efficiency	I-4.1.3-1	"
Cavitating head loss	I-4.1.3-2	10 March 1967
Oxidizer Boost Turbine		
H vs Q	I-4.1.3-3	10 March 1967
Efficiency	I-4.1.3-3	"
Fuel Boost Turbine		
H vs Q	I-4.2.3-1	10 March 1967
Efficiency	I-4.2.3-1	"
5. Boost pump suction pressures set for minimum NPSH values.	Paragraph 2.3.1	
Main pump suction pressures set for nominal values (by adjusting boost pump speeds).		
6. Oxidizer and fuel seal flows per TPA design values.	Figure 2.6-1, dated 10 March 1967	
7. Line and passage fluid resistances per maximum allocated values (minimum Kw).	Table 2.6-2, 24 August 1966	

Table I-2.7-1 (cont.)

Module Assembly

Parameter	Symbol	Units	Value
Thrust	F	lb	100,000
Specific Impulse (Sea Level)	I_s	sec	285
Mixture Ratio (1)	M.R	-	2.373
Efficiency, Specific Impulse	η_{I_s}	%	91.64
Oxidizer Weight Flow	$\dot{W}_{OSBP}$	lb/sec	246.9
Fuel Weight Flow	$\dot{W}_{FSBP}$	lb/sec	104.0
Total Weight Flow	$\dot{W}_T$	lb/sec	350.9
Fuel Suction Pressure	P_{FSBP}	psia	19.5
Oxidizer Suction Pressure	P_{OSBP}	psia	36.6

Secondary Combustor

Parameter	Symbol	Units	Value
Chamber Pressure, Plenum	P_{SC}	psia	2,800
Combustion Efficiency	η_c	-	96.3
Nozzle Efficiency	η_N	-	95.2
Mixture Ratio, Injector	$M.R._{SC}$	-	2.20
Fuel Flow, Injector	$\dot{W}_{FSC}$	lb/sec	85.2
Gas Weight Flow to Injector	$\dot{W}_{GSC}$	lb/sec	247.7

(1) Includes film cooling

10 March 1967

Table I-2.7-1 (cont.)

Secondary Combustor (cont.)

Parameter	Symbol	Units	Value
Oxidizer Flow Regen. Cooling	$\dot{W}_{ORG}$	lb/sec	221.9
Oxidizer Film Cooling	$\dot{W}_{OFC}$	lb/sec	18.0
Maximum Regen. Coolant Capability	ϕ_{SC}	Btu/in.^{2} sec	15.6
Throat Area	A_{TSC}	in.^{2}	21.35
Area Ratio	ϵ	-	20
Pressure Ratio (Sea Level)	R_{PSC}	-	190.5
Characteristic Length	L^*_{SC}	in.	40
Temperature Rise Regen. Coolant	ΔT_{ORG}	°F	118
Pressure Drop Regen. Coolant Tube	ΔP_{ORG}	psi	776
Characteristic Velocity (2)	c^*_{SC}	ft/sec	5482
Thrust Coefficient (2)	C_F	-	1.673

Primary Combustor

Parameter	Symbol	Units	Value
Chamber Pressure, Injector Face	P_{PC}	psia	4679
Gas Temperature	T_{PC}	°F	1218
Mixture Ratio	MR_{PC}	-	11.55
Oxidizer Flow	$\dot{W}_{OPC}$	lb/sec	211.9
Fuel Flow	$\dot{W}_{FPC}$	lb/sec	18.3
Propellant Total Flow	$\dot{W}_{TI}$	lb/sec	230.2
Characteristic Velocity	c^*_{PC}	ft/sec	2399
Specific Heat Ratio	k_{PC}	-	1.256
Molecular Weight	M_{PC}	lb/mole	33.4

(2) Based on geometric throat area and engine total flow.

10 March 1967

Table I-2.7-1 (cont.)

Main Turbopump - Pumps

Parameter	Symbol Fuel	Symbol Oxidizer	Units	Value Fuel	Value Oxidizer
Propellant Temperature	T_{FSM-1}	T_{OSM}	°F	80.6	82.5
Propellant Temperature	T_{FSM-2}			89.5	
Propellant Specific Weight	γ_{FSM-1}	γ_{OSM}	lb/ft^3	56.0	89.2
Propellant Specific Weight	γ_{FSM-2}			56.3	
Shaft Speed	N_T		rpm	40000	40000
Total Suction Pressure	P_{FSM-1}	P_{OSM}	psia	135	257
Total Suction Pressure	P_{FSM-2}		psia	3334	
Net Positive Suction Head	$NPSH_{FSM}$	$NPSH_{OSM}$	ft	339	382
Total Discharge Pressure	P_{FDM-1}	P_{ODM}	psia	3694	5989
Total Discharge Pressure	P_{FDM-2}		psia	5857	
Head (Noncavitating)	H_{FDM-1}	H_{ODM}	ft	9200	9341
Head	H_{FDM-2}		ft	6449	
Weight Flow	$\dot{W}_{FSM-1}$	$\dot{W}_{OSM}$	lb/sec	124.1	287.[illegible]
Weight Flow	$\dot{W}_{FSM-2}$		lb/sec	21.0	
Volume Flow	Q_{FSM-1}	Q_{OSM}	gpm	995	1446
Volume Flow	Q_{FSM-2}		gpm	167	
Ratio Pump to engine flow	$R_{\dot{W}FSM-1}$	$R_{\dot{W}OSM}$	-	1.194	1.165
Ratio Q/N	Q_{FSM-1}/N_T	Q_{OSM}/N_T	gpm/rpm	0.02487	0.03615
Ratio Q/N	Q_{FSM-2}/N_T		gpm/rpm	0.00418	

10 March 1967

Table I-2.7-1 (cont.)

Main Turbopump - Pumps (cont.)

Parameter	Symbol: Fuel	Symbol: Oxidizer	Units	Value: Fuel	Value: Oxidizer
Specific Speed	N_{SFM-1}	N_{SOM}	$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	1343	1601
Specific Speed	N_{SFM-2}		$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	719	
Ratio H/N^2 (Noncavitating)	H_{FDM-1}/N_T^2	H_{ODM}/N_T^2	ft/rpm^2	5.750×10^{-6}	5.838×10^{-6}
Ratio H/N^2	H_{FDM-2}/N_T^2		ft/rpm^2	4.031×10^{-6}	
Efficiency	η_{FM-1}	η_{OM}	%	65.3	73.3
Efficiency	η_{FM-2}		%	57.0	
Shaft Power	SHP_{FM-1}	SHP_{OM}	hp	3161	6598
Shaft Power	SHP_{FM-2}		hp	433	
Suction Specific Speed	S_{FM-1}	S_{OM}	$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	15954	17604
Suction Specific Speed	S_{FM-2}		$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	584	

10 March 1967

Table I-2.7-1 (cont.)

Main Turbopump - Turbine

Parameter	Symbol	Units	Value
Pressure, Inlet Total	P_{TIT}	psia	4,556
Temperature, Inlet Total	T_{TIT}	°F	1,218
Pressure Ratio, total to static	R_{PT}	-	1.500
Static Back Pressure	P_{TES}	psia	3,037
Temperature, exit total	T_{TET}	°F	1,111
Gas Flow	$\dot{W}_{TI}$	lb/sec	230.2
Shaft Speed	N_T	rpm	40,000
Shaft Power	SHP_T	hp	10,192
Efficiency, turbine	η_T	%	80.4

Table I-2.7-1 (cont.)

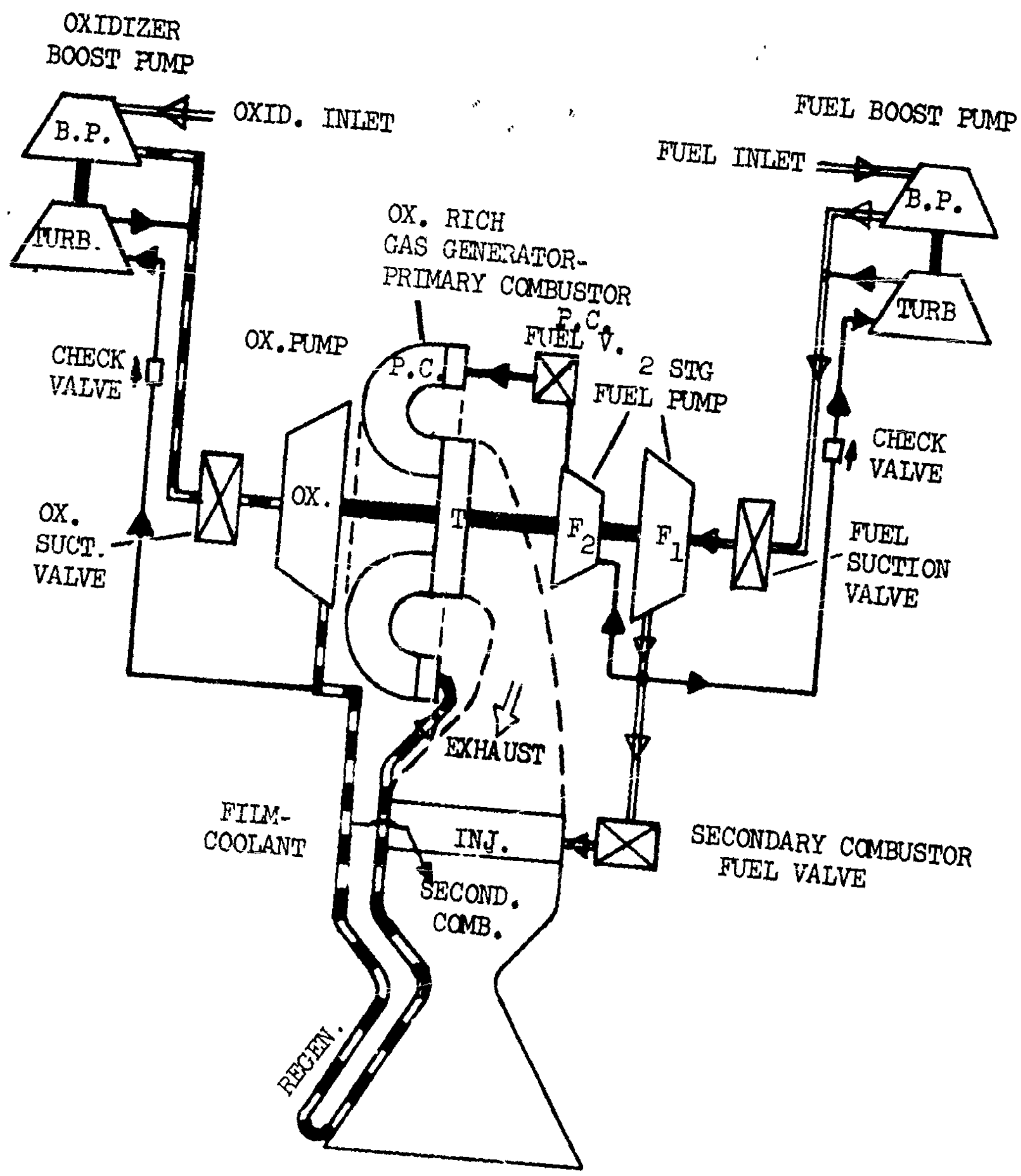
Boost Pump - Pump

Parameter	Symbol		Units	Value	
	Fuel	Oxidizer		Fuel	Oxidizer
Propellant Temperature	T_{FSBP}	T_{OSBP}	°F	77	77
Propellant Specific Weight	γ_{FSBP}	γ_{OSBP}	lb/ft^3	56.1	69.5
Total Suction Pressure	P_{FSBP}	P_{OSBP}	psia	19.5	36.6
Net Positive Suction Head	$NPSH_{FSBP}$	$NPSH_{OSBP}$	ft	43.2	30.6
Shaft Speed	N_{FTBP}	N_{OTBP}	rpm	7976	7981
Total Discharge Pressure	P_{FDBP}	P_{ODBP}	psia	174	311
Head (Noncavitating)	H_{FDBP}	H_{ODBP}	ft	398	443
Weight Flow	$\dot{W}_{FSBP}$	$\dot{W}_{OSBP}$	lb/sec	104.0	246.9
Volume Flow	Q_{FSBP}	Q_{OSBP}	gpm	832	1,238
Ratio Q/N	Q_{FS}/N_{FTBP}	Q_{OS}/N_{OTBP}	gpm/rpm	0.1043	0.1551
Specific Speed	N_{SFBP}	N_{SOBP}	$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	2,582	2,909
Ratio H/N^2 (Noncavitating)	$\frac{H_{FDBP}}{N_{FTBP}^2}$	$\frac{H_{ODBP}}{N_{OTBP}^2}$	$\frac{ft}{rpm^2}$	6.255	6.952
Efficiency, Pump	η_{FBP}	η_{OBP}	%	65.0	64.8
Shaft Power	SHP_{FBP}	SHP_{OBP}	hp	116	306
Suction Specific Speed	S_{FBP}	S_{OBP}	$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	13,652	21,586

Table I-2.7-1 (cont.)

Boost Pump - Hydraulic Turbine

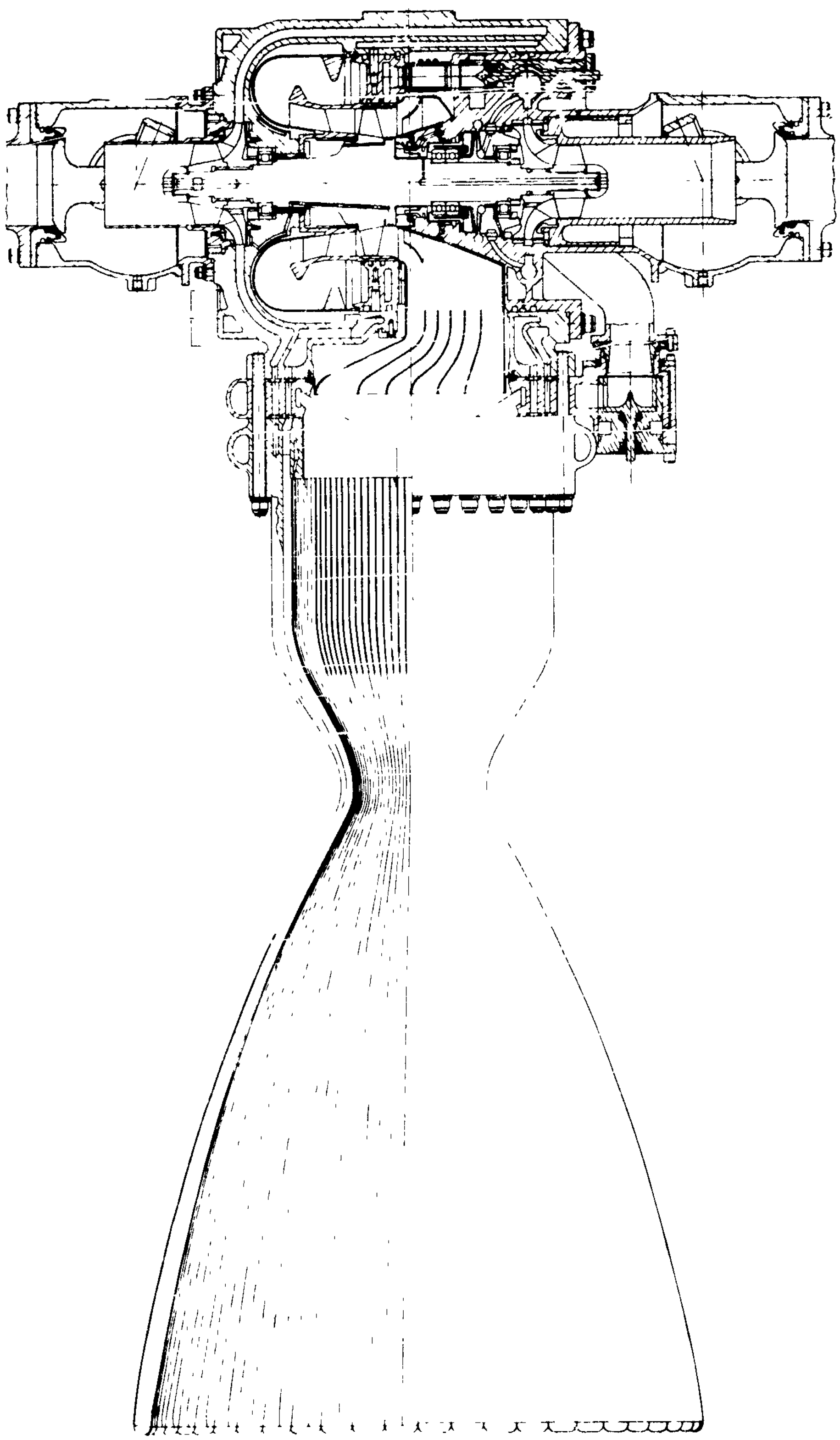
Parameter	Symbol		Units	Value	
	Fuel	Oxidizer		Fuel	Oxidizer
Pressure, Inlet Total	P_{TITFBP}	P_{TITOBP}	psia	3,358	5,516
Temperature Inlet Total	T_{TITFBP}	T_{TITOBP}	°F	89.5	94.4
ΔPressure	ΔP_{TFBP}	ΔP_{TOBP}	psi	3226	5254
Static Back Pressure	P_{TEFBP}	P_{TEOBP}	psia	132	262
Flow, Turbine Drive	$\dot{W}_{FTBP}$	$\dot{W}_{OTBP}$	lb/sec	17.9	40.6
Shaft Speed	N_{FTBP}	N_{OTBP}	rpm	7,976	7,981
Shaft Power	SHP_{FTBP}	SHP_{OTBP}	hp	116	306
Efficiency, Turbine	η_{FTBP}	η_{OTBP}	%	43.1	50.4



ARES System Staged Combustion Cycle (u)
Advanced Turbopump Configuration

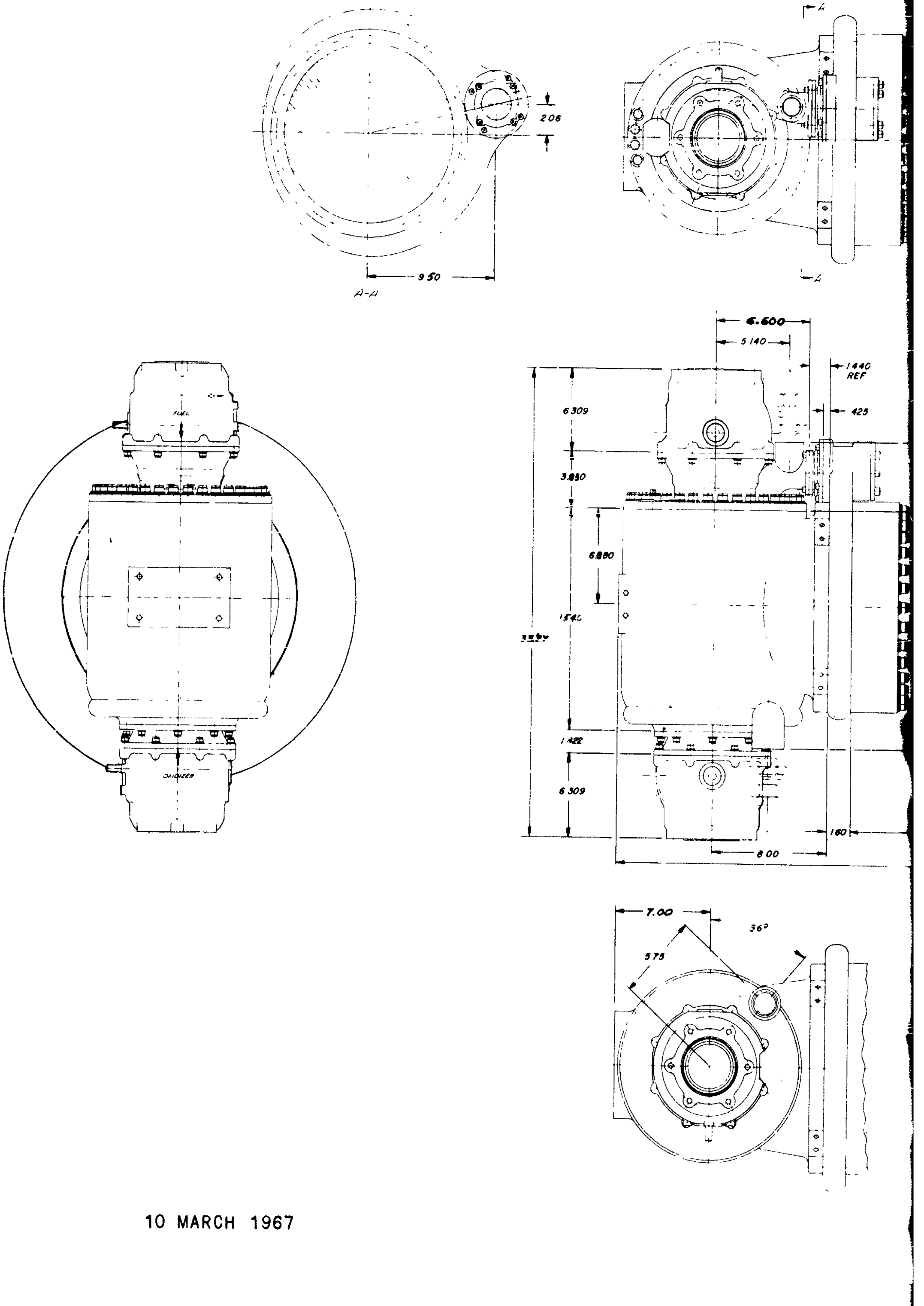
29 October 1965

Figure I-2.1-1

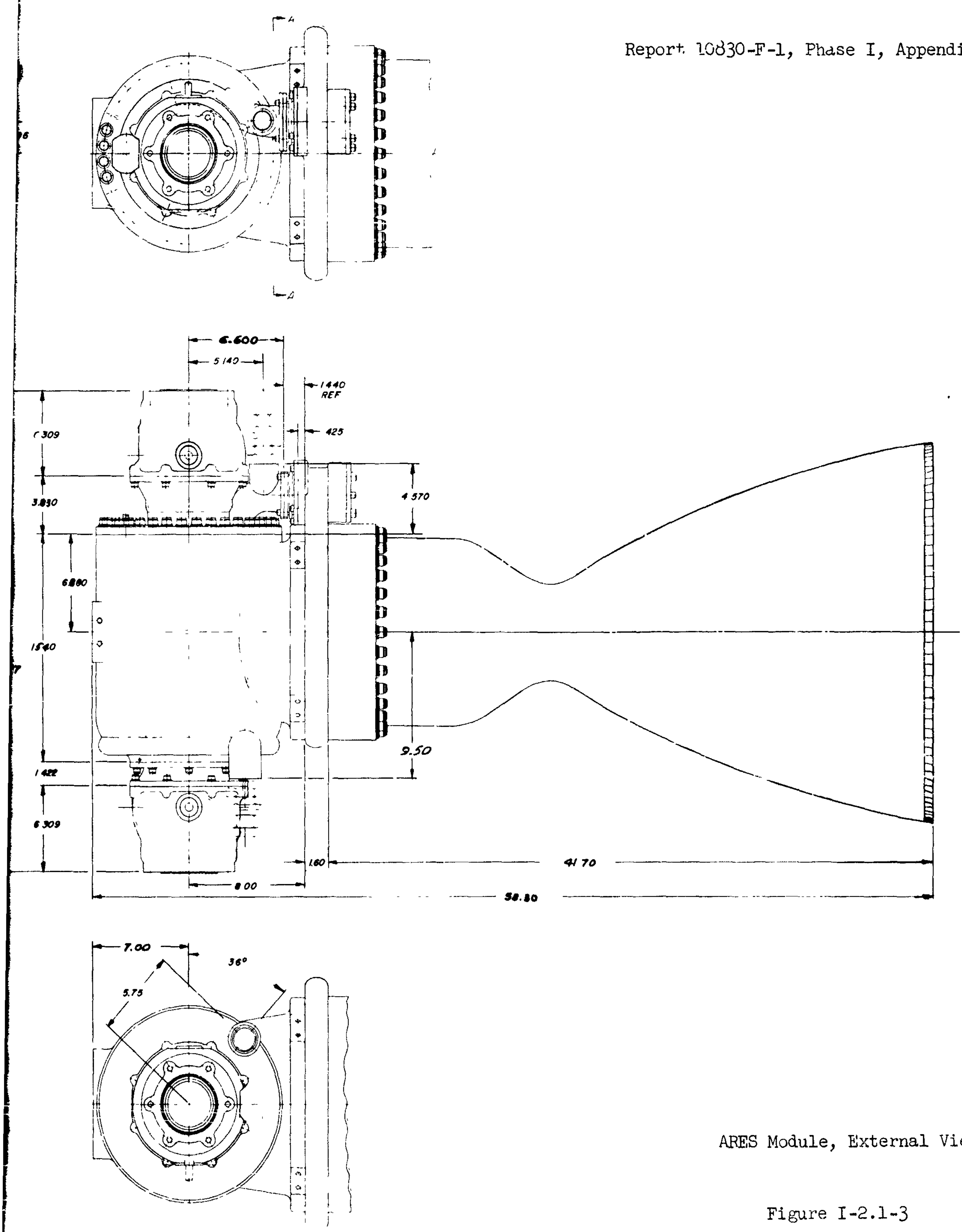


[illegible] Module Subassembly [illegible]

Figure I-2.1-2

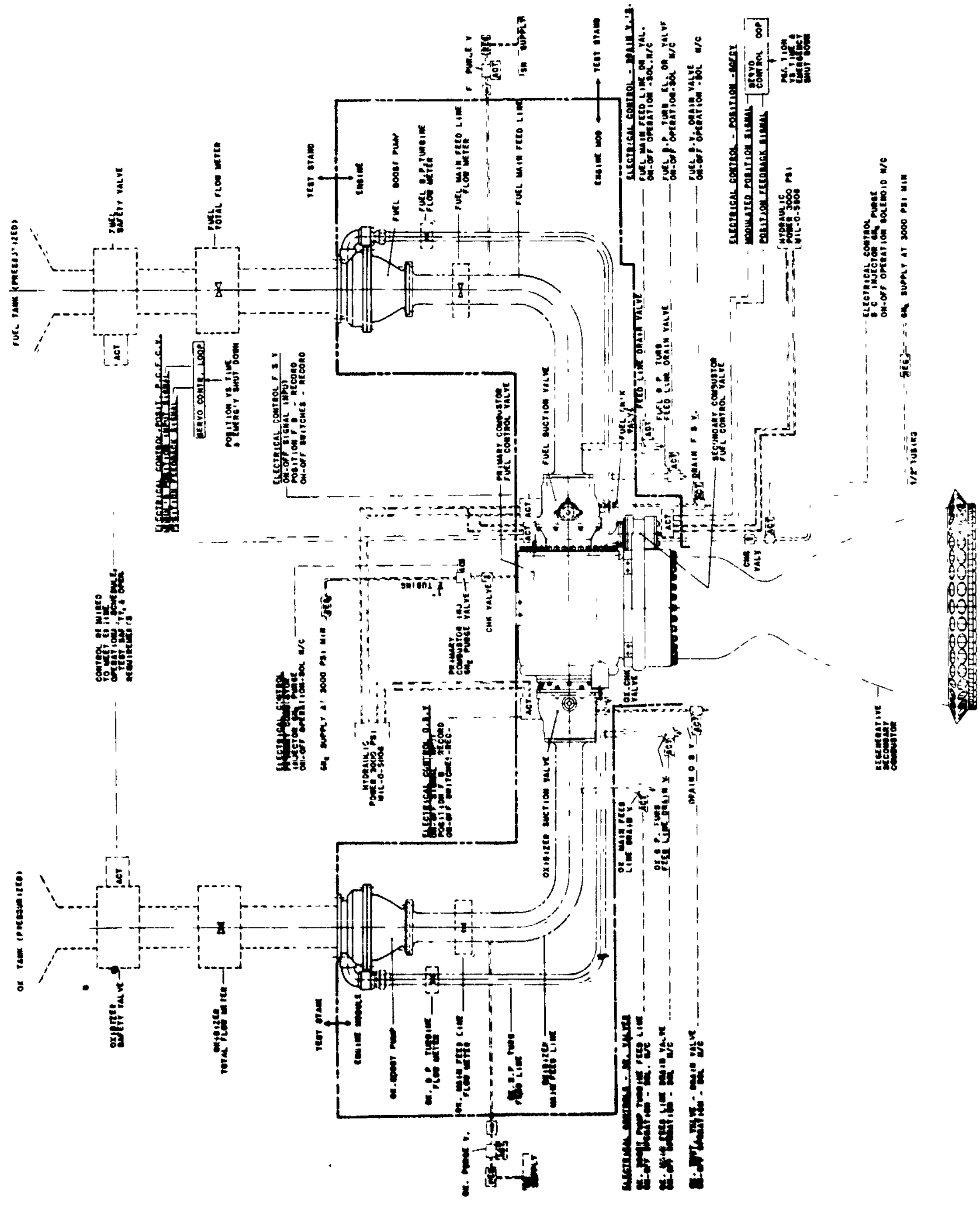


10 MARCH 1967



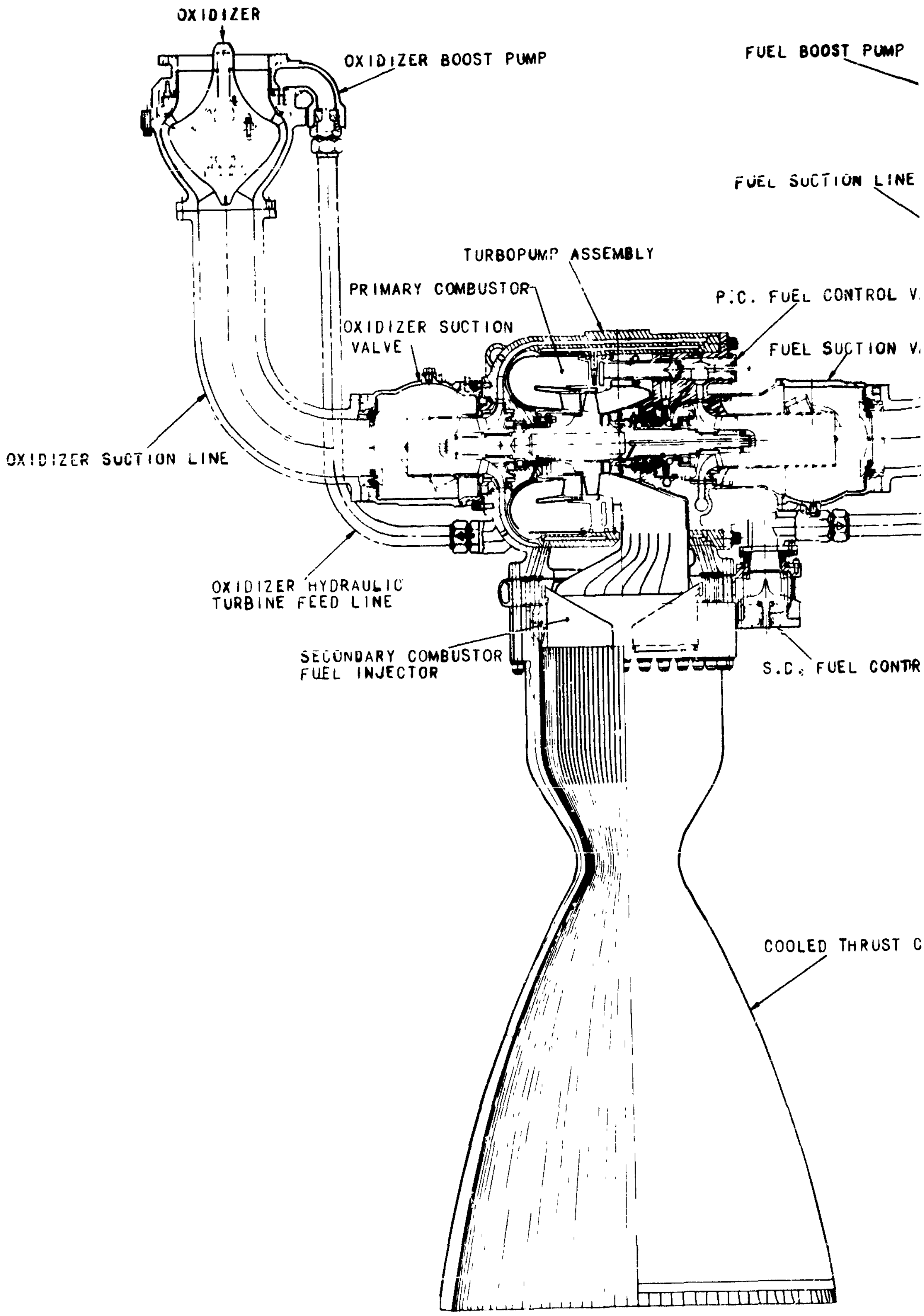
ARES Module, External View

Figure I-2.1-3



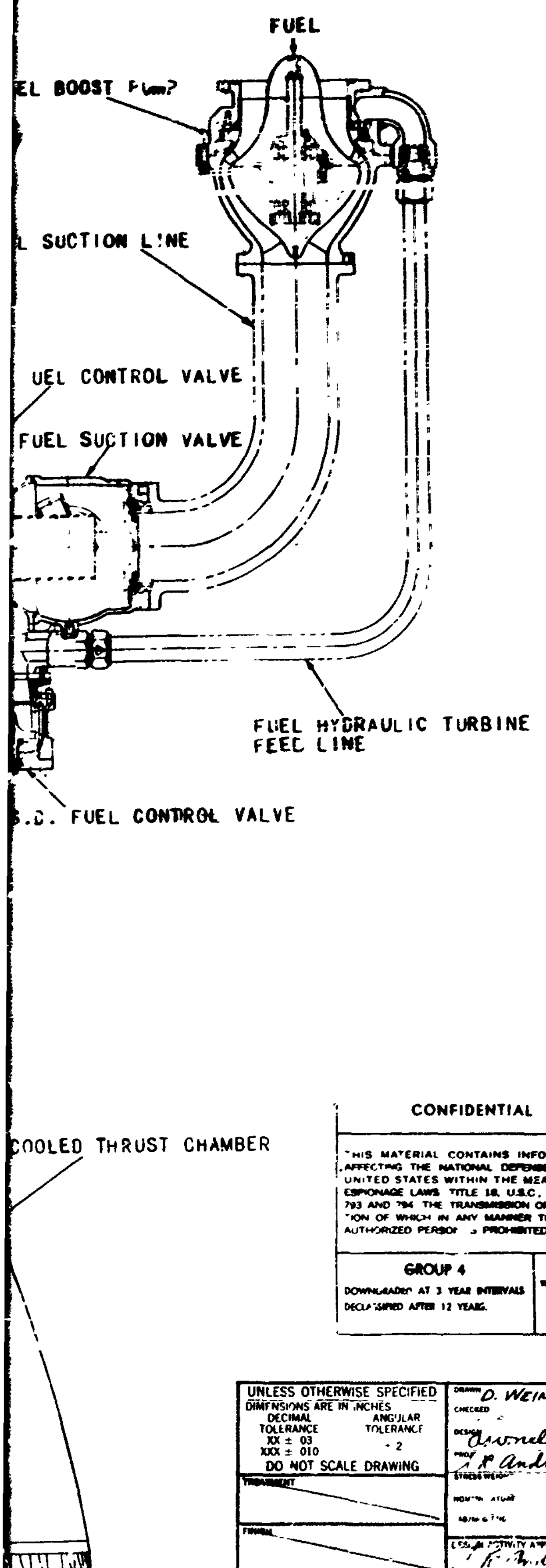
ARES Module Assembly Test Installation Interface

Figure I-2.1-4



DRAWING LEVEL

10 MARCH 1967



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DECLASSIFIED AFTER 12 YEARS.

WORK ORDER NO. 0947

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DECIMAL TOLERANCE XX ± .03 XXX ± .010
ANGULAR TOLERANCE ± 2
DO NOT SCALE DRAWING

DRAWN D. WEINTZ 7-14-66
DESIGN Arnelson 7-14-66
PROJ R. Andrus 7-14-66
DESIGN ACTIVITY APPD R. Andrus 7-14-66

AEROJET-GENERAL CORPORATION
LIQUID ROCKET PLANT SACRAMENTO CALIFORNIA

TITLE ADVANCED STORABLE ENGINE - DEMONSTRATOR (U)

CODE IDENT NO 05824 DWG SIZE F DWG NO 1132072

SCALE None RELEASE DATE 2 16 67

DRAWING LEVEL O

Figure I-2.1 5

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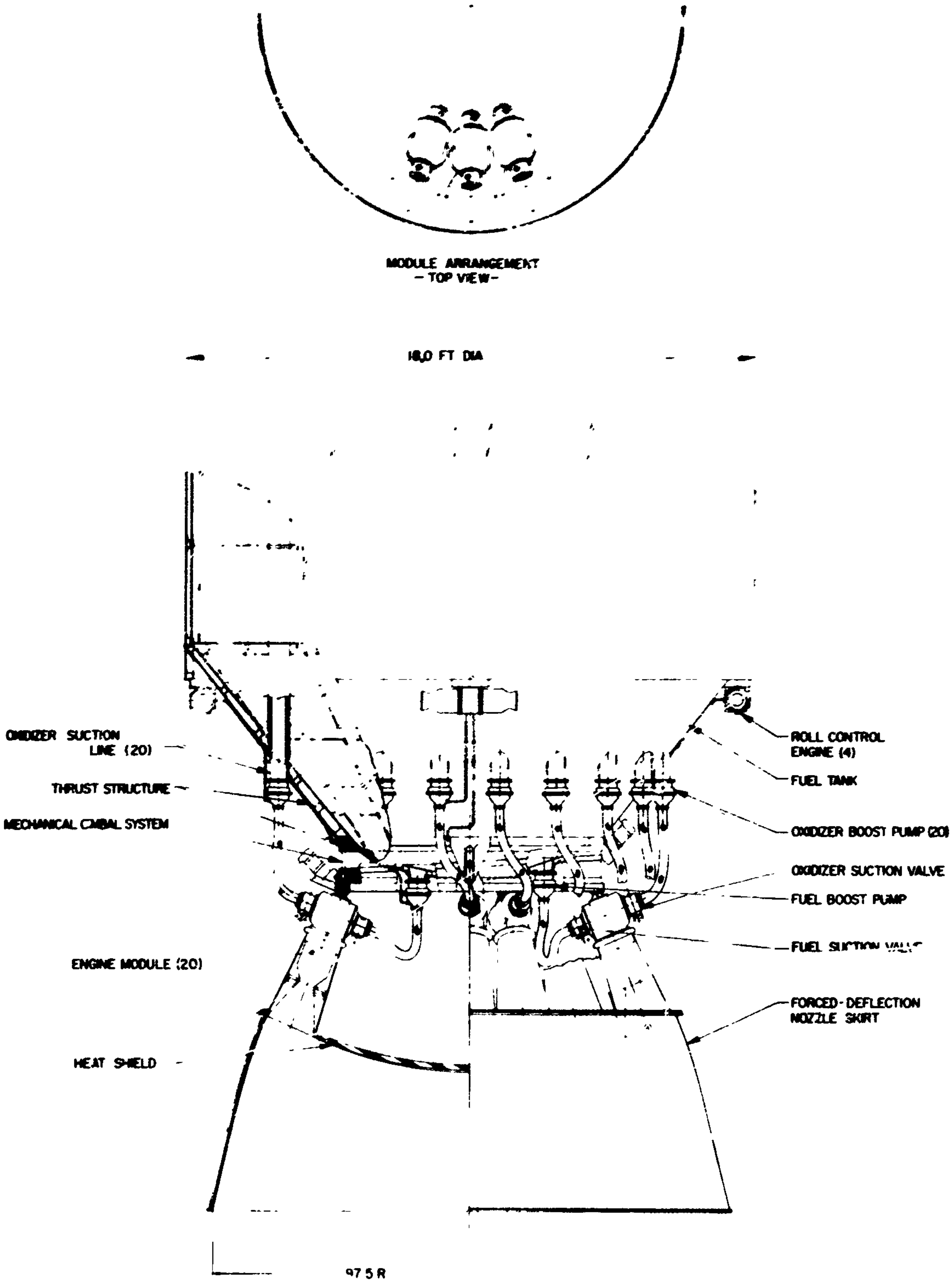
Report 10830-F-1, Phase I, Appendix I



Propulsion System
20-Module Forced Deflection Nozzle (u)

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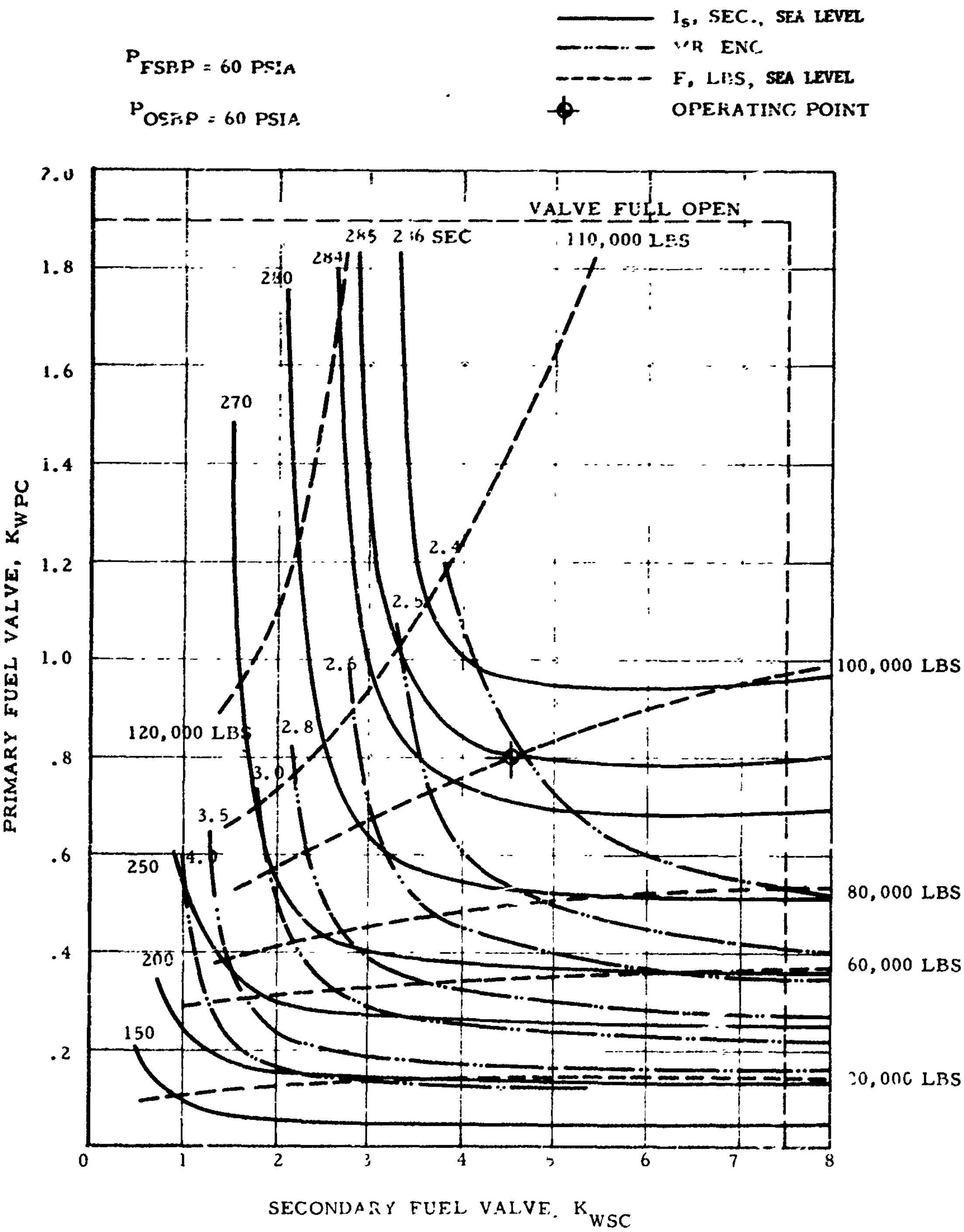
Figure I-2.2-1

Report 10830-F-1, Phase I, Appendix I

MODULE ASSEMBLY
PREDICTED CONTROL CHARACTERISTICS (u)



10 March 1967

Figure I-2.4.1-1

PRIMARY COMBUSTOR
PREDICTED CONTROL CHARACTERISTICS (u)

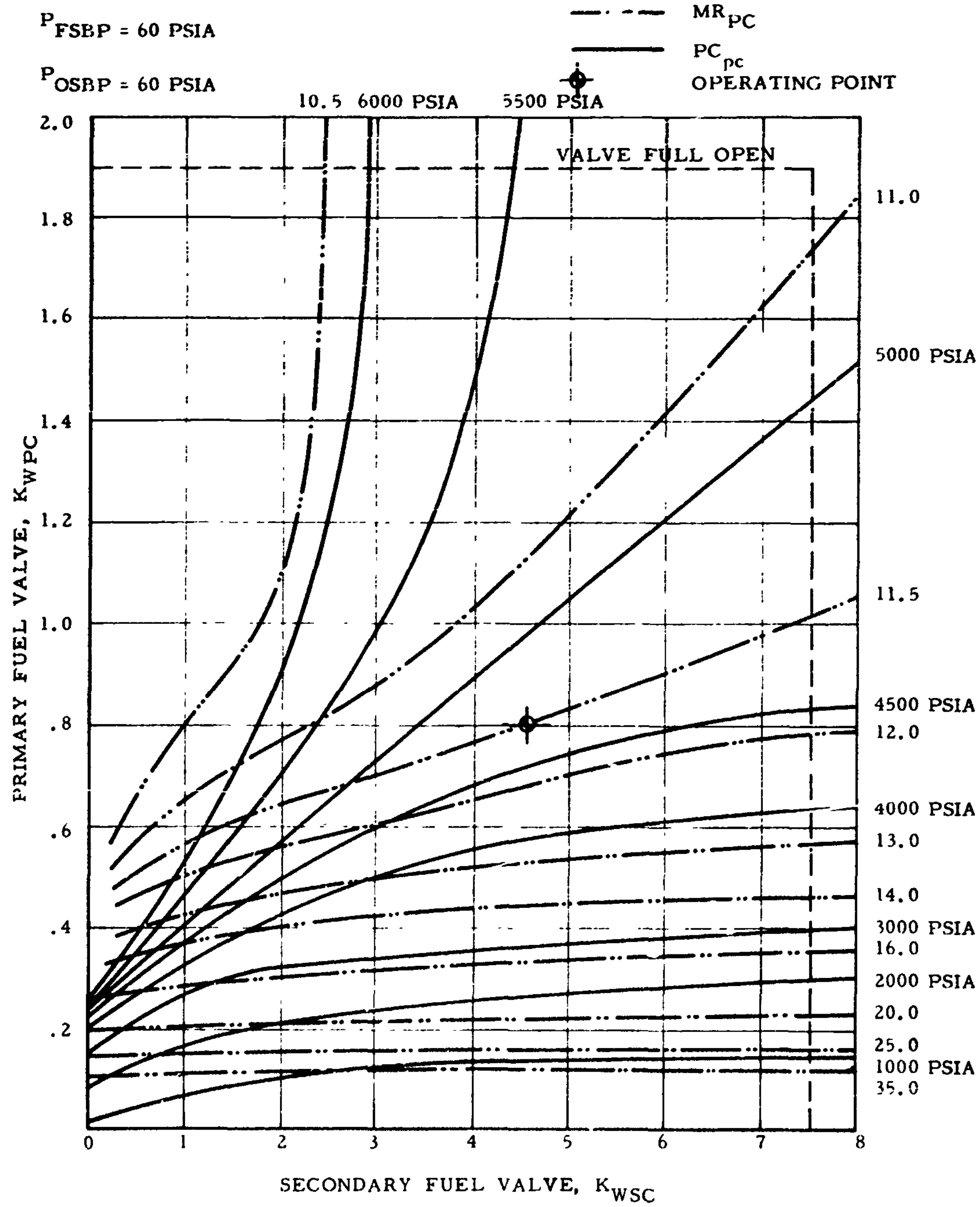


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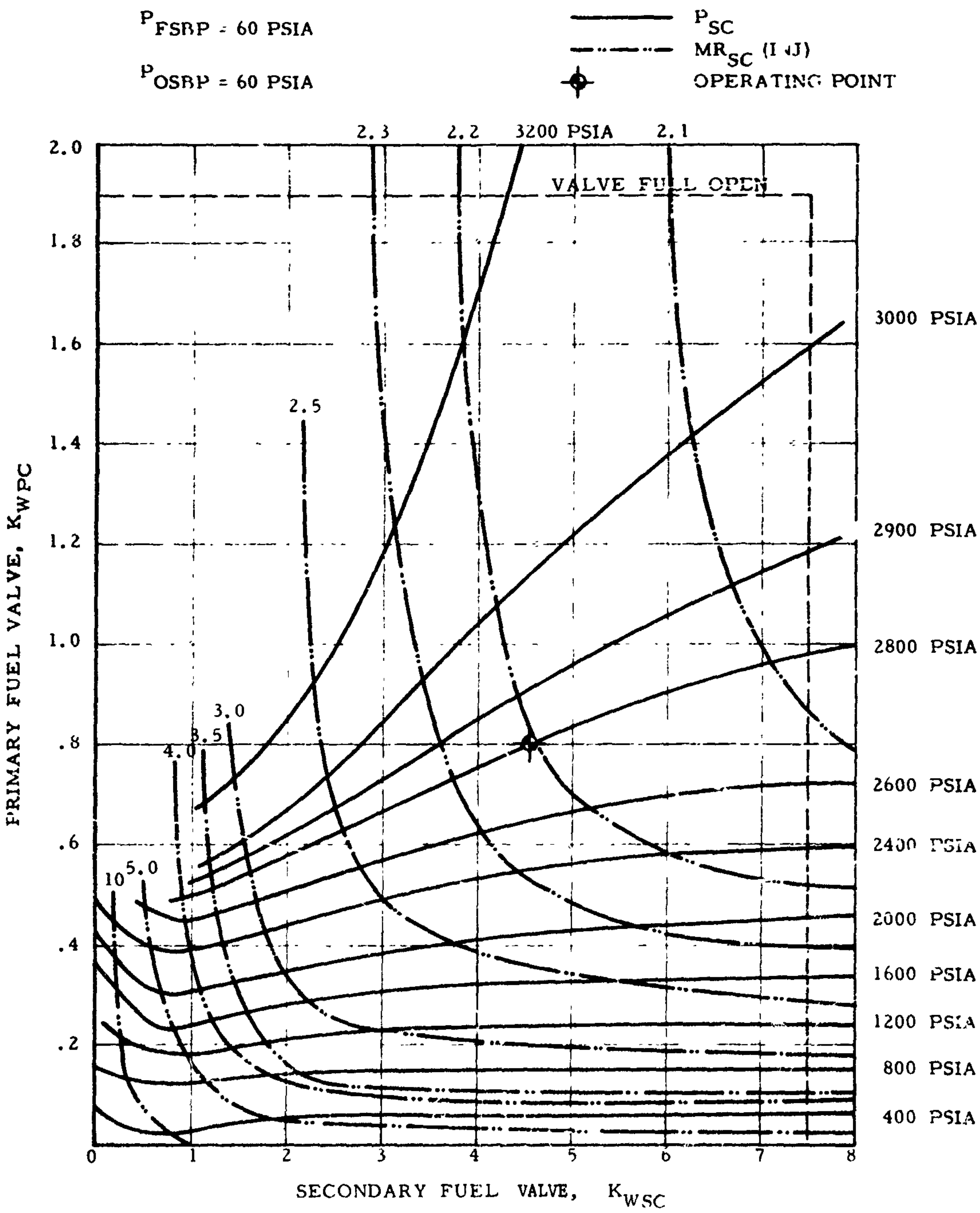
Figure I-2.4.1-2

Report 10830-F-1, Phase I, Appendix I

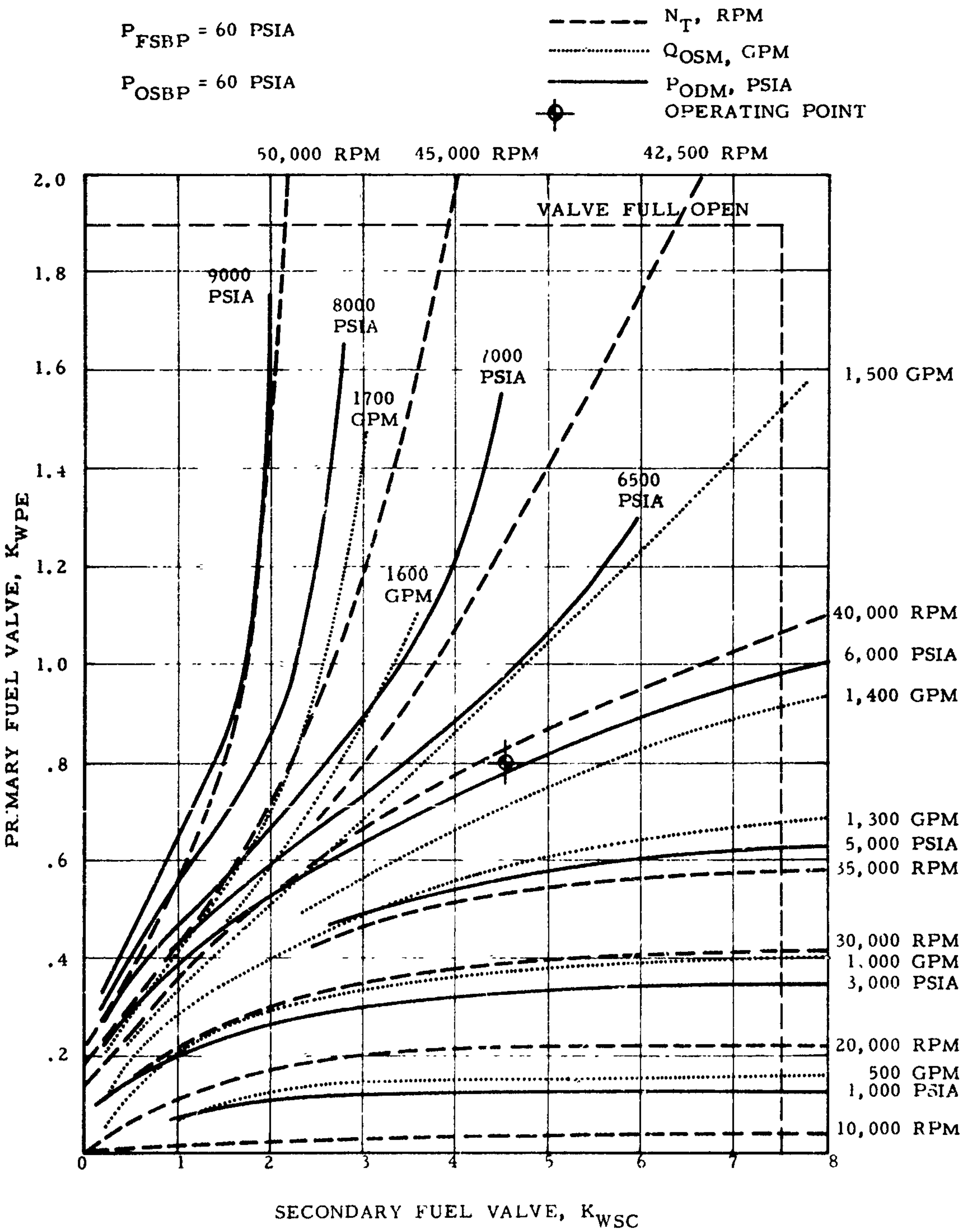
SECONDARY COMBUSTOR
PREDICTED CONTROL CHARACTERISTICS (U)



23 SEPT 1966

Figure I-2.4.1-3

OXIDIZER PUMP
PREDICTED CONTROL CHARACTERISTICS (u)



23 SEPT 1966

Figure I-2.4.1-4

FIRST STAGE FUEL PUMP
PREDICTED CONTROL CHARACTERISTICS (u)

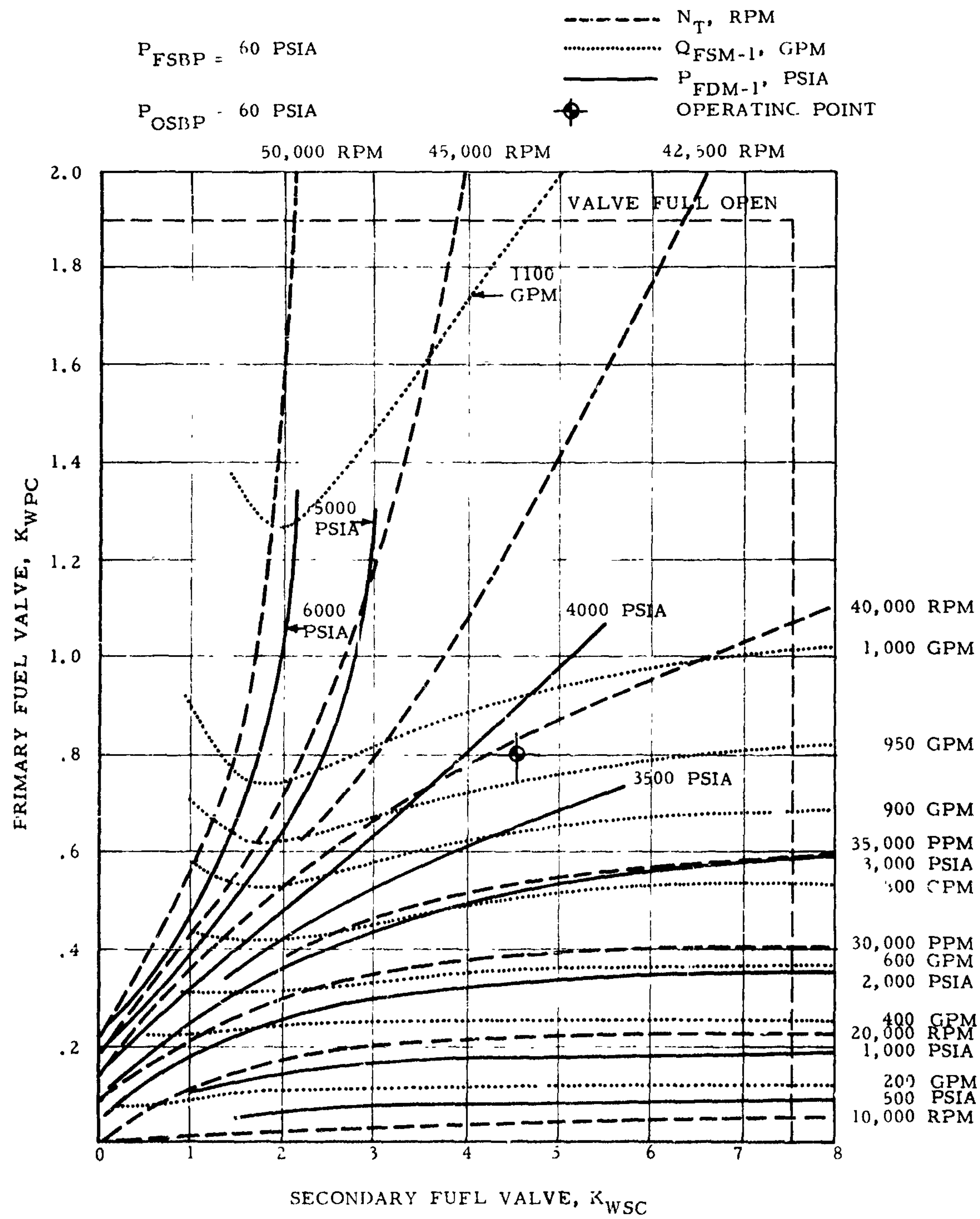


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Figure I-2.4.1-5

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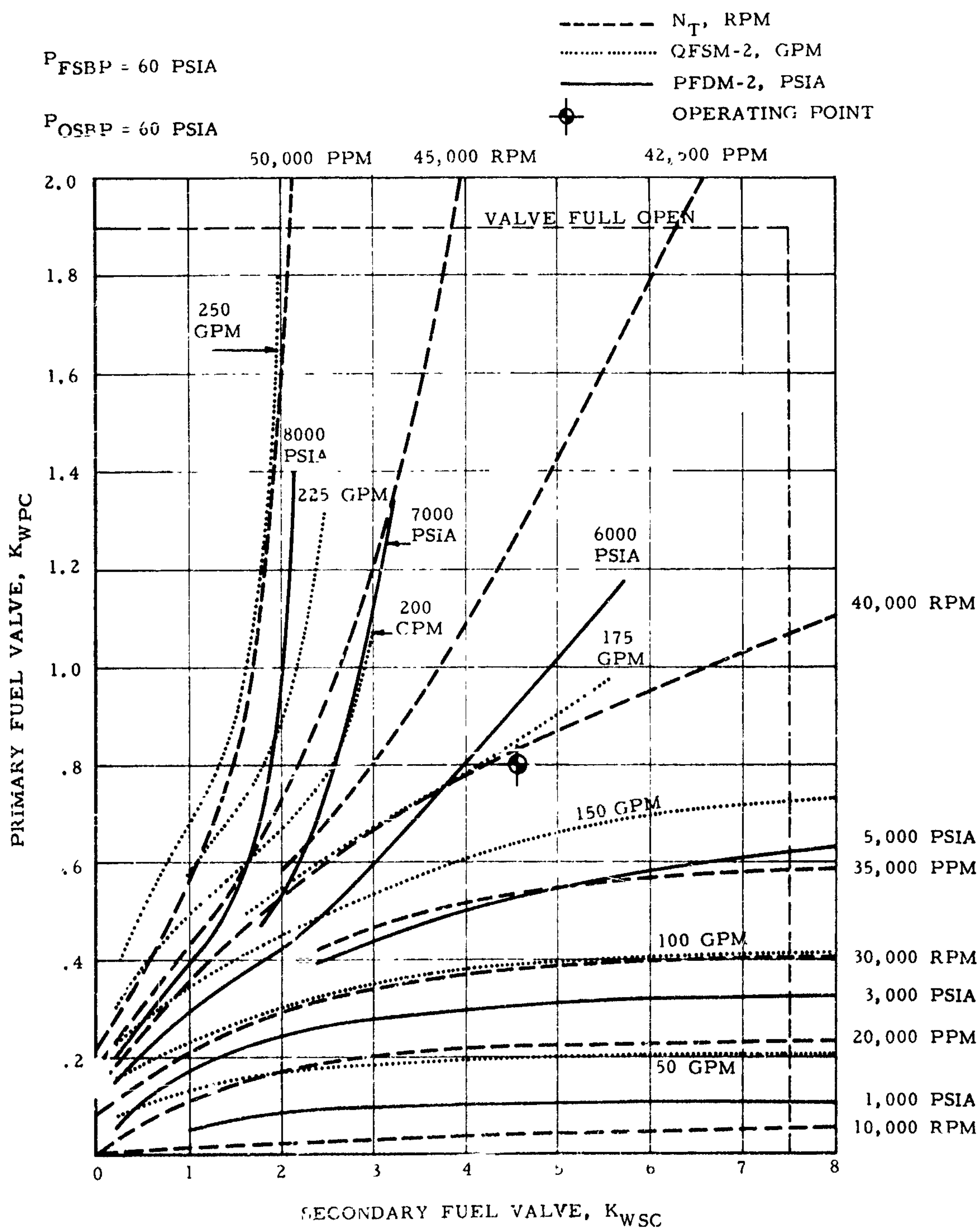
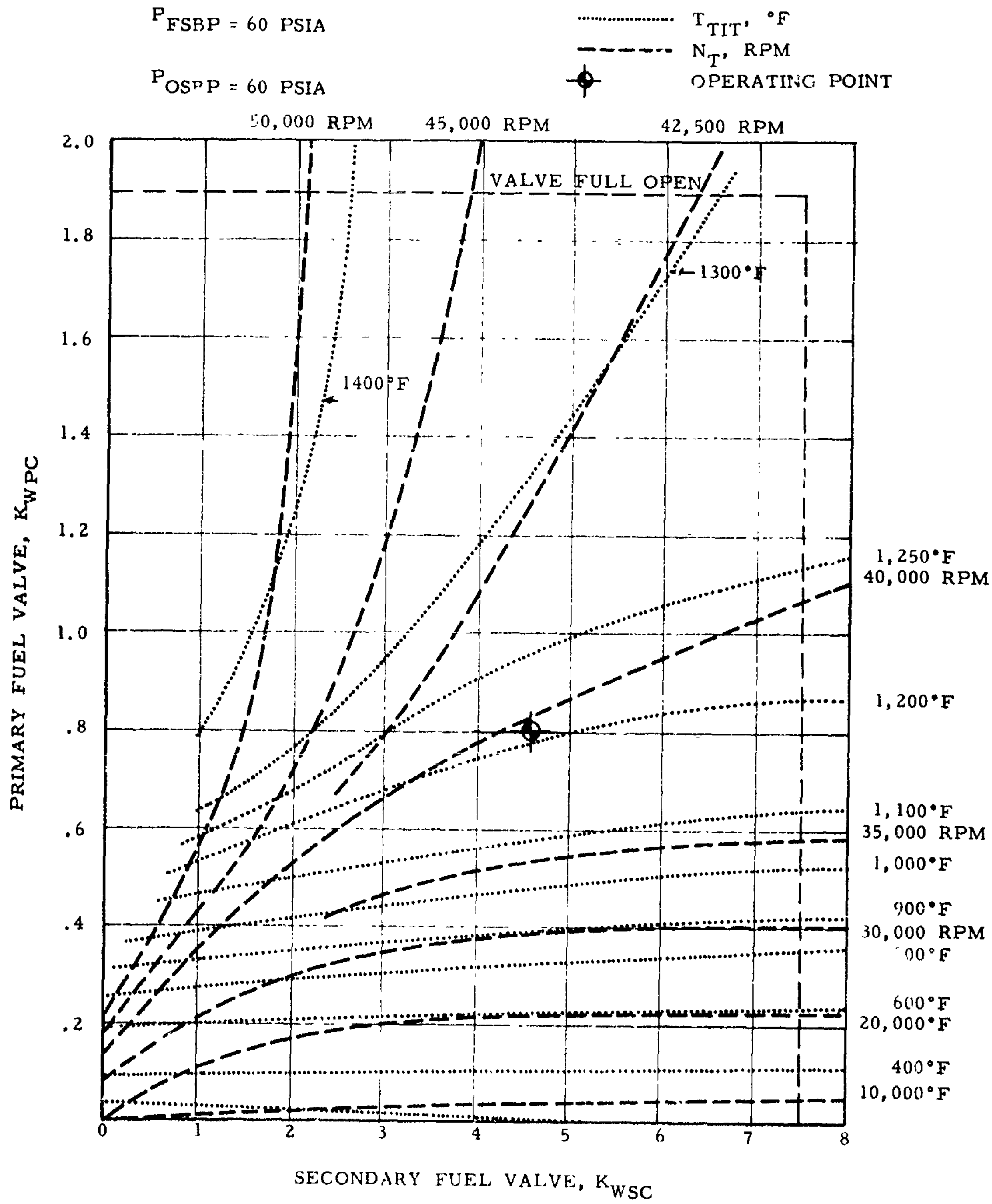
SECOND STAGE FUEL PUMP
PREDICTED CONTROL CHARACTERISTICS (u)



23 SEPT 1966

Figure I-2.4.1-6

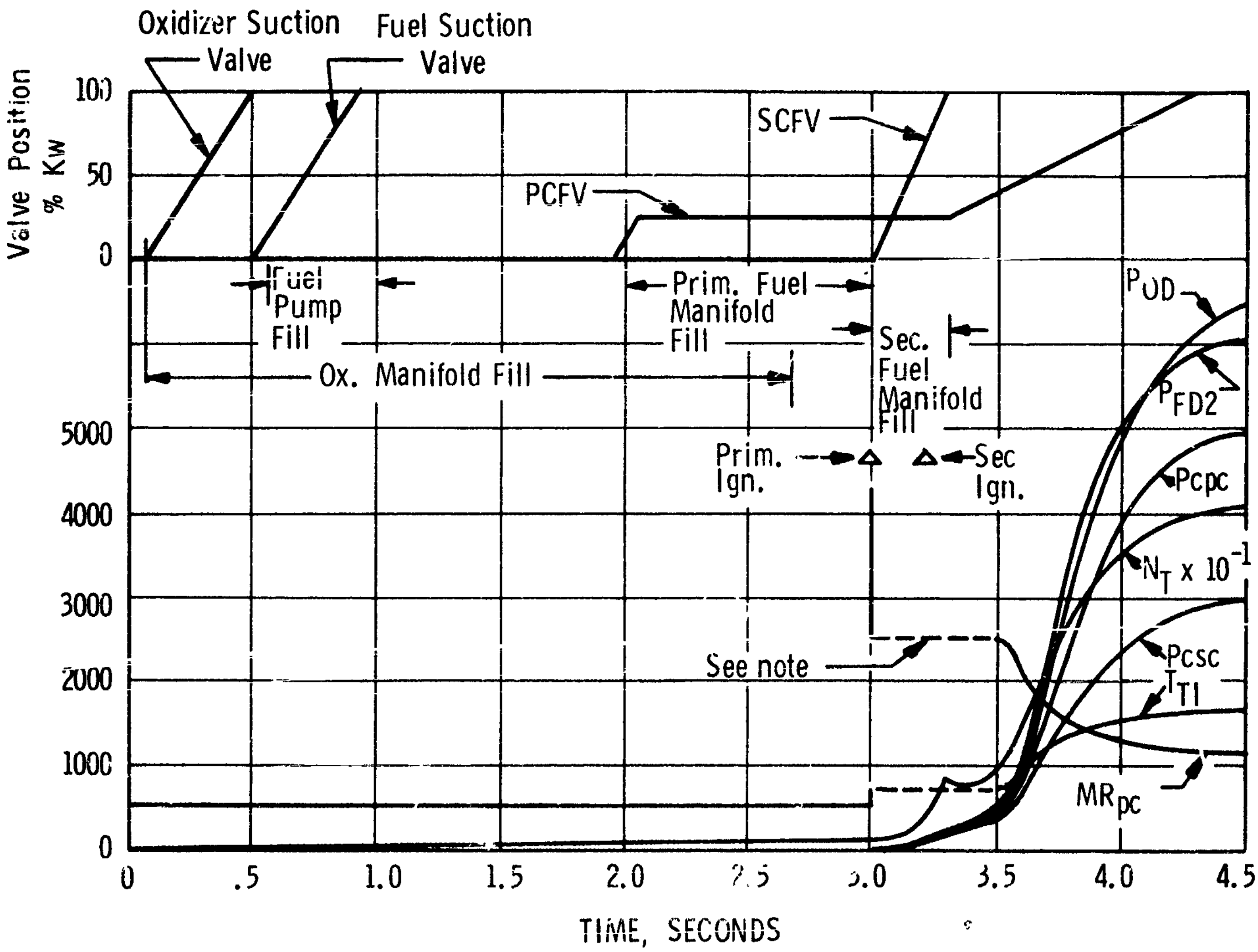
MAIN DRIVE TURBINE
PREDICTED CONTROL CHARACTERISTICS (u)



23 SEPT 1966

Figure I-2.4.1-7

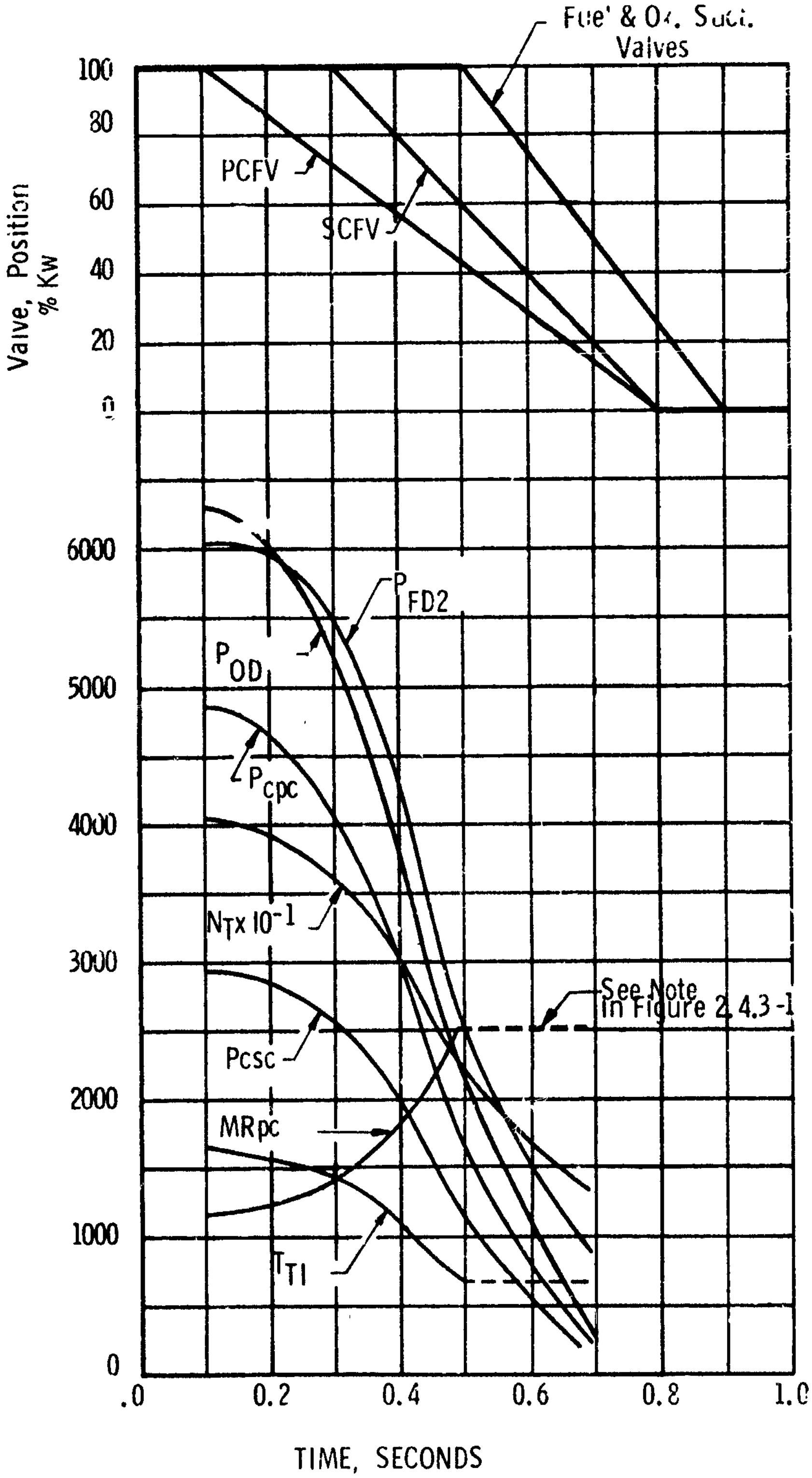
Note: Primary combustor mixture ratio (MR_{pc}) was limited to maximum of 25:1, pending chemical model and test data for this region.



Module Start Transient (U)

10 March 1967

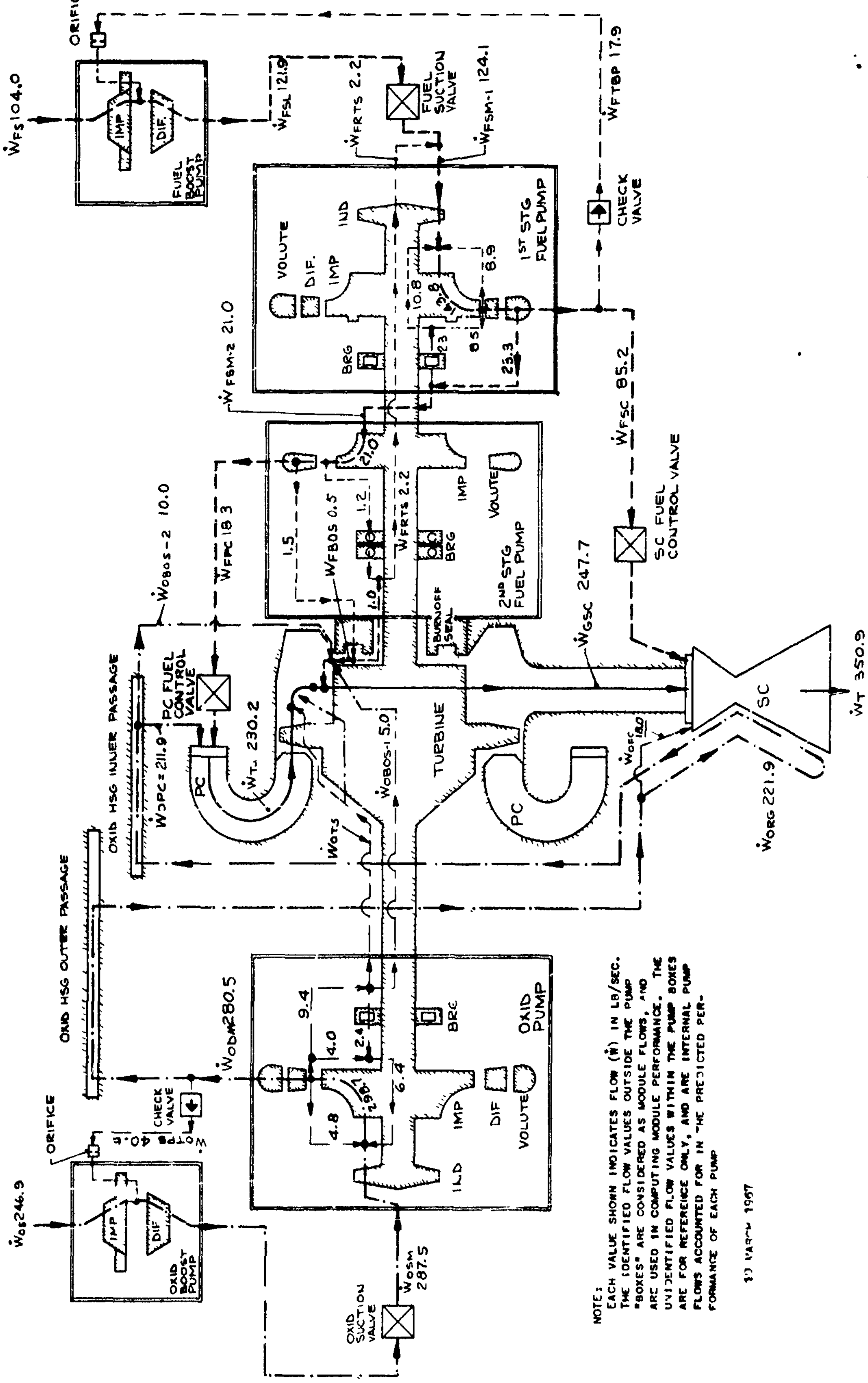
Figure I-2.4.3-1



Module Shutdown Transient (U)

10 March 1967

Figure I-2.4.4-1



ARES System Flow Schematic (U)

Figure I-2.6-1

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PREDICTED MODULE PERFORMANCE VS. FILM COOLANT FLOW (u)

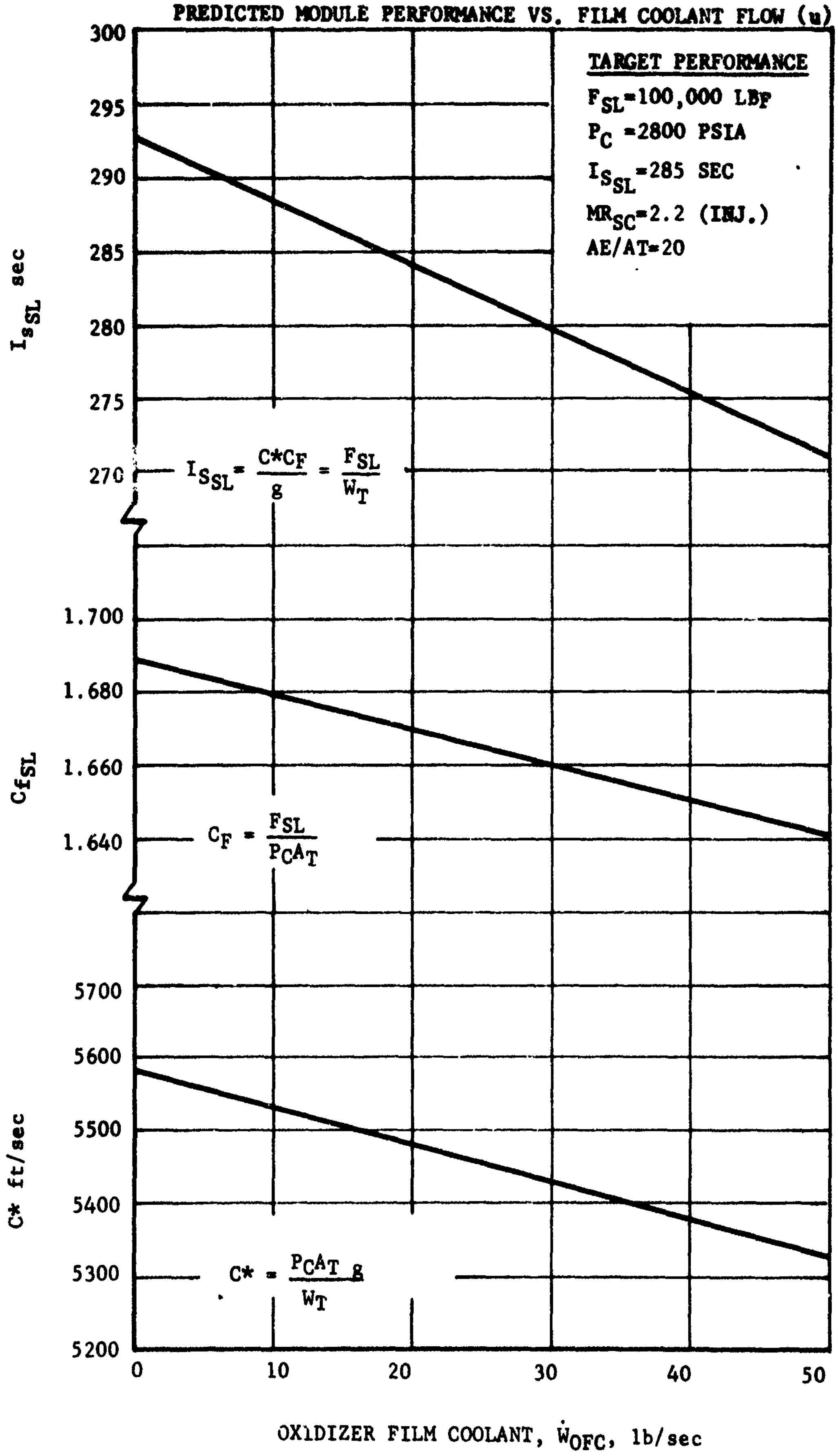

Figure I-2.7-1

10 March 1967

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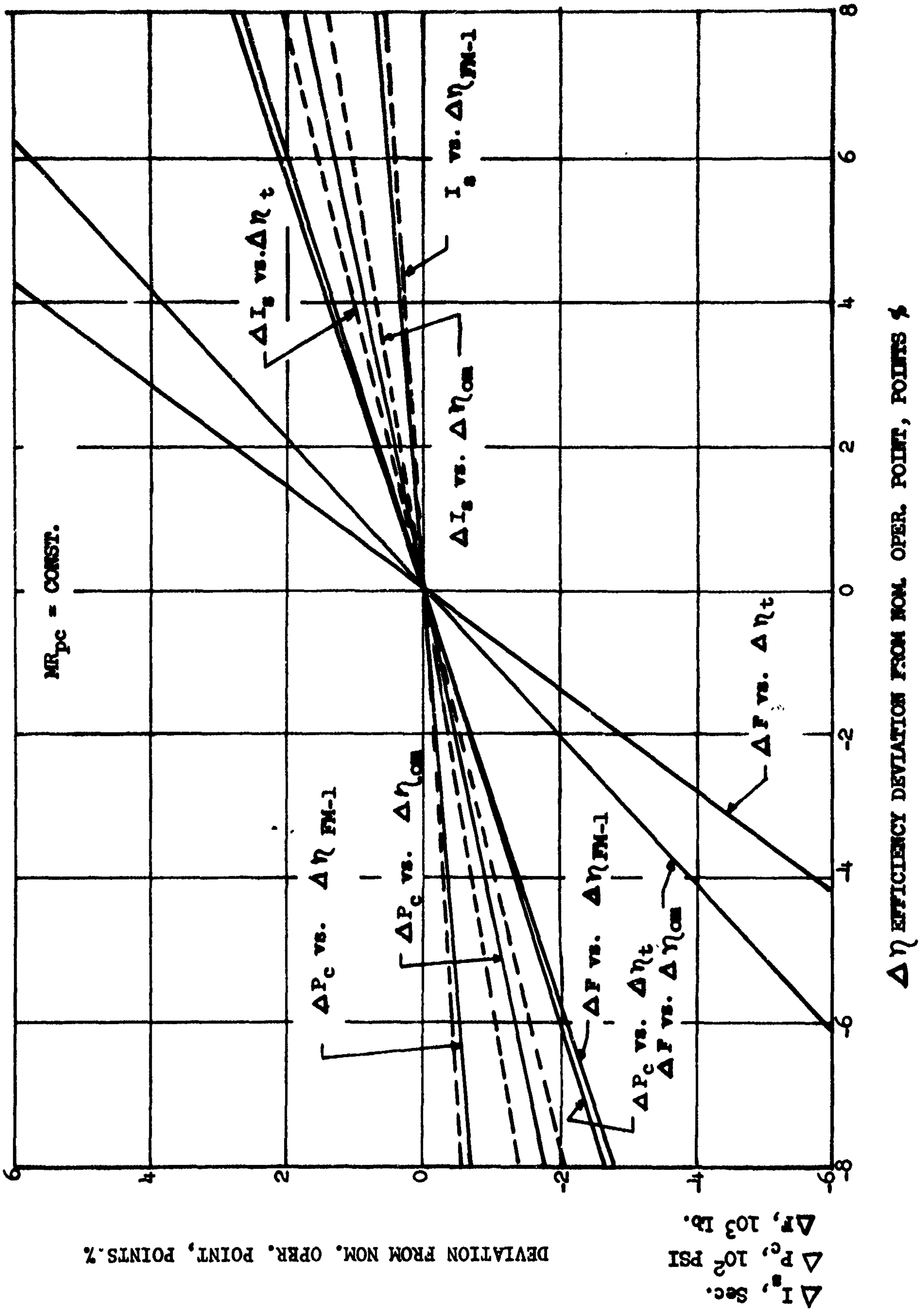
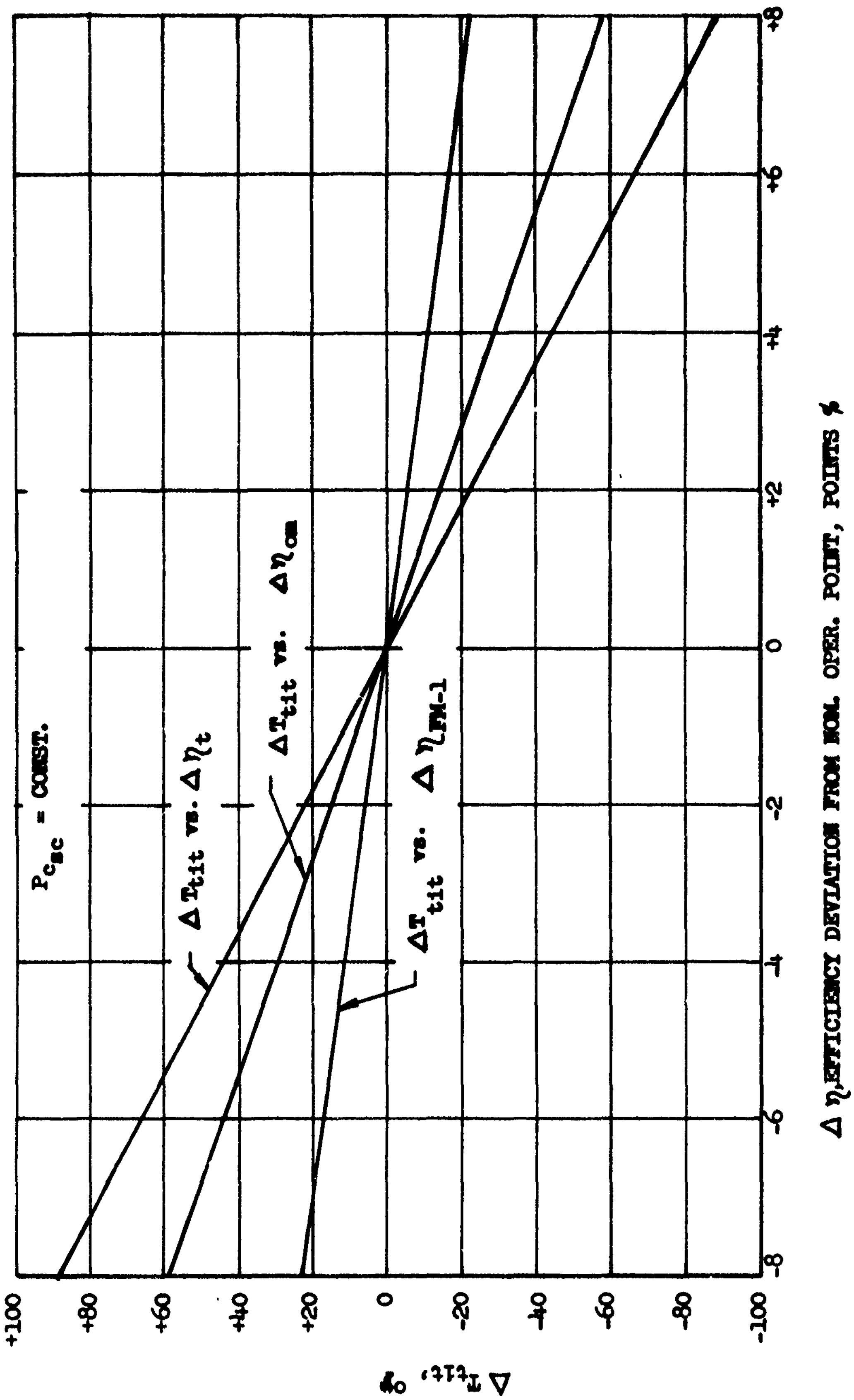


Effects of Turbopump Component Efficiency Deviations on Engine Performance

Figure I-2.7-2



Effects of Turbopump Component Efficiency Deviations on Turbine Inlet Temperature

Figure I-2.7-3

TURBINE THROAT AREA INFLUENCE
ON PERFORMANCE (u)

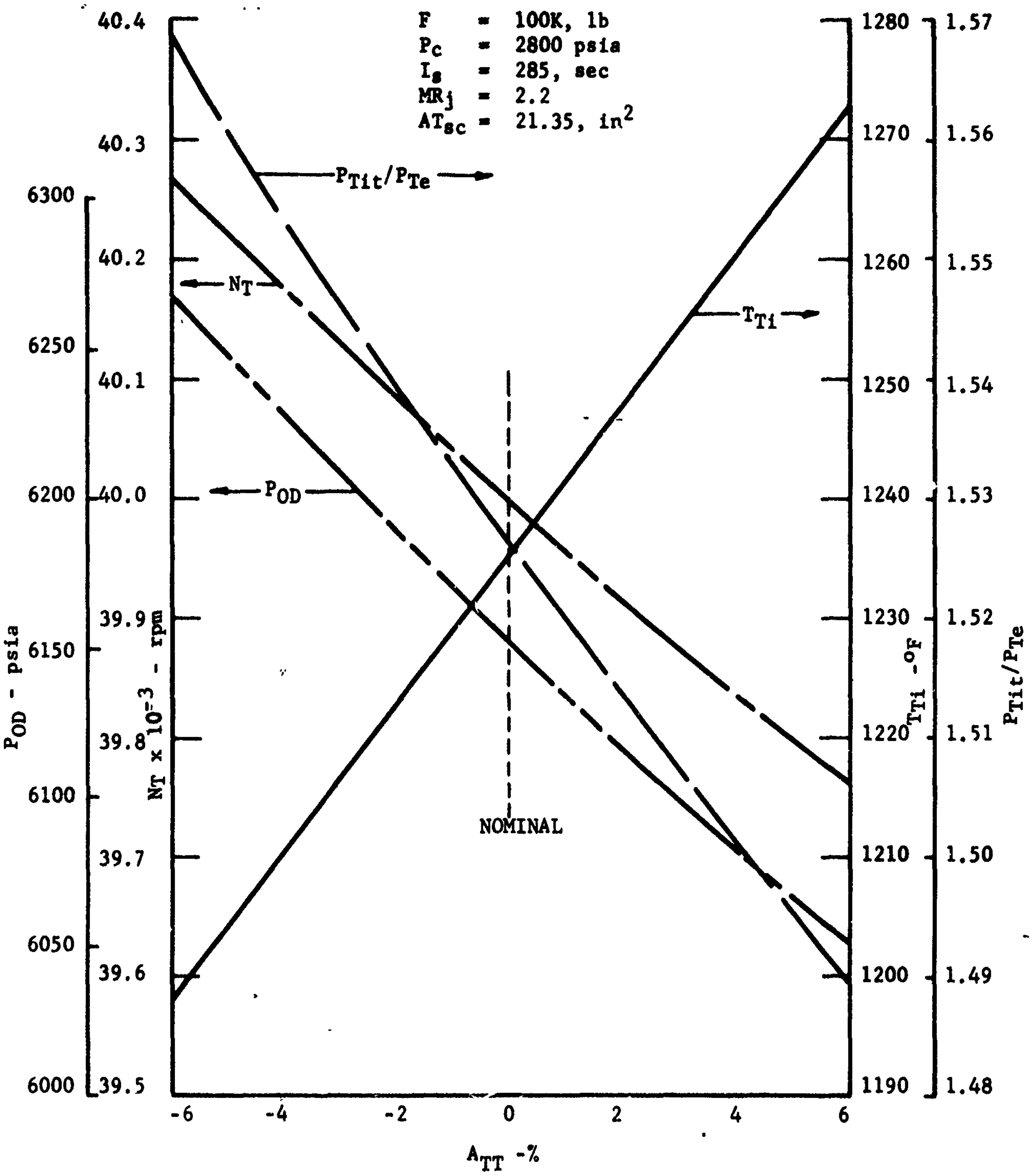


Figure I-2.7-4

ARES STEADY STATE OPERATING REGION (U)
I_s = 285 SEC (PHASE II TARGET)
MR_{sc} = 2.2
ϵ = 20:1

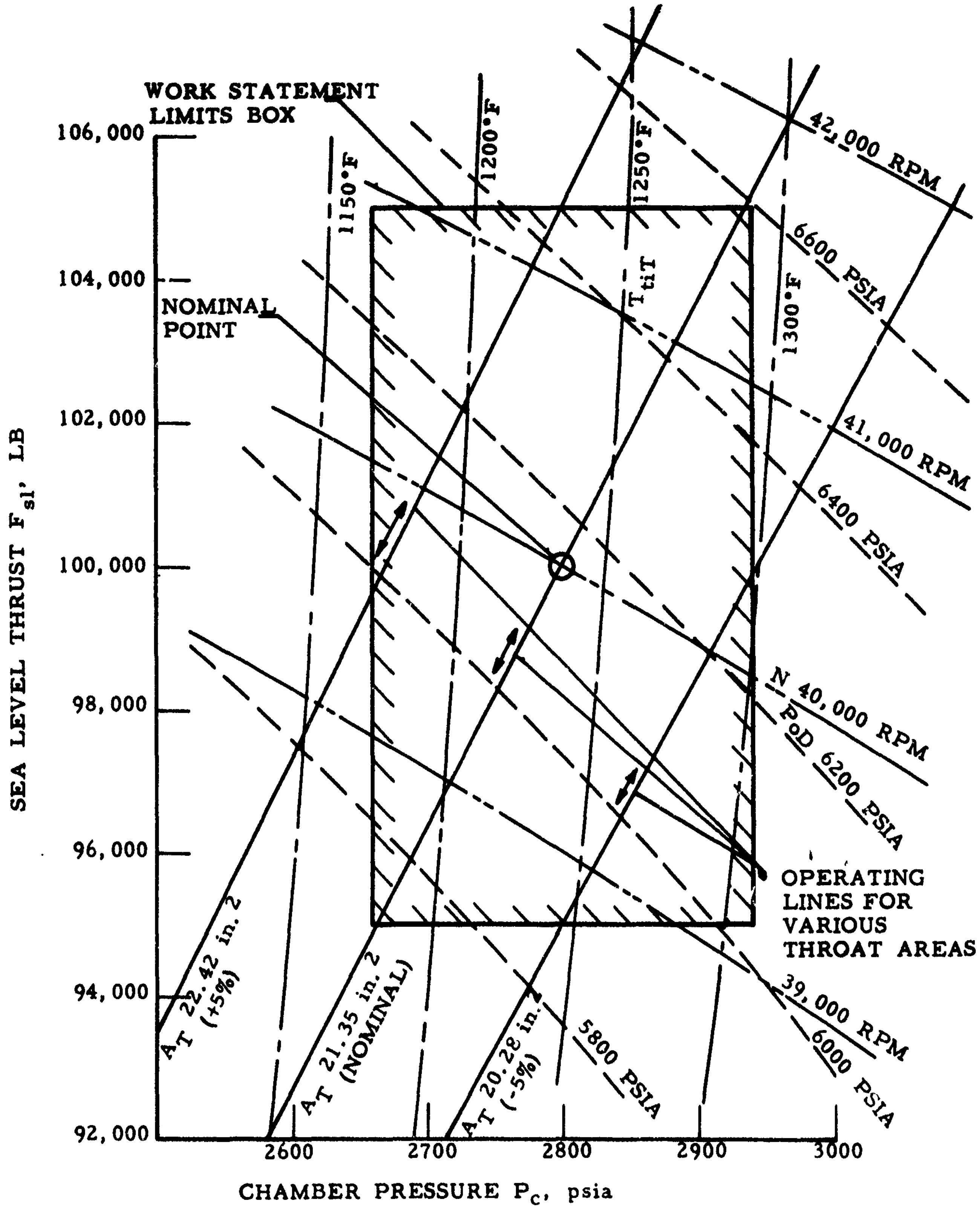
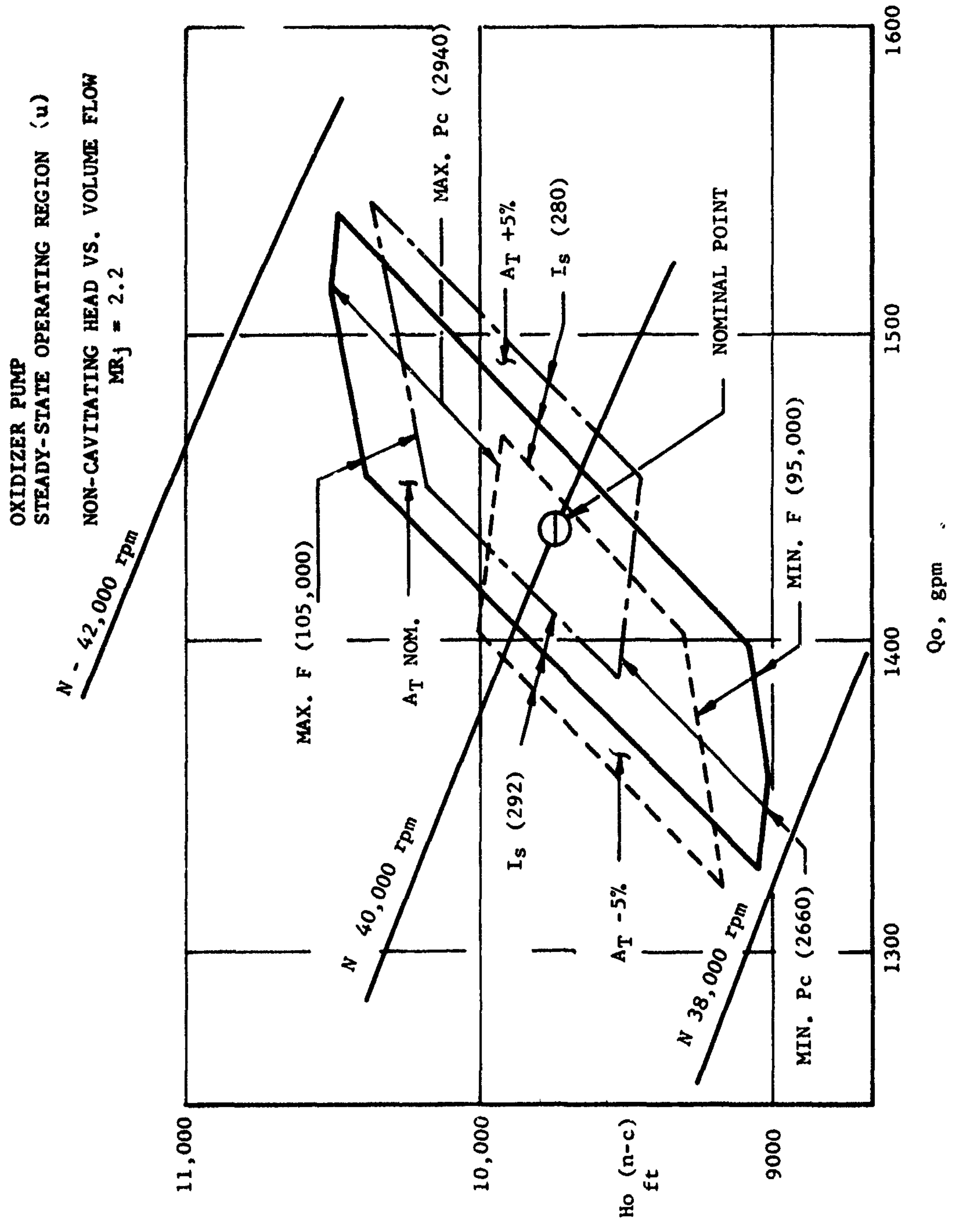


Figure I-2.7-5


OXIDIZER PUMP
STEADY-STATE OPERATING REGION (u)
NON-CAVITATING HEAD VS. VOLUME FLOW
MRj = 2.2
N - 42,000 rpm
N 40,000 rpm
N 38,000 rpm
MAX. F (105,000)
MIN. F (95,000)
MAX. Pc (2940)
MIN. Pc (2660)
AT NOM.
AT +5%
AT -5%
Is (280)
Is (292)
NOMINAL POINT
11,000
10,000
9000
Ho (n-c) ft
1300
1400
1500
1600
Qo, gpm

3.0 TURBOPUMP ASSEMBLY - ADVANCED

3.1 TURBOPUMP ASSEMBLY

3.1.1 Description

The turbopump assembly configuration is shown on a isometric cutaway view in Figure I-3.1.1-1. The design layout displaying axial stack-up, radial stack-up, detail part numbers with material selection, and instrumentation are shown in Figures I-3.1.1-2, I-3.1.1-3, I-3.1.1-4 and I-3.1.1-5, respectively. Predicted flow distribution of the turbopump, which was used to establish the component design specification, is shown in Figure I-3.1.1-6. A back-up design is described in Section 9.0

3.1.2 Specification

The turbopump assembly target operating point flow and pressure schedules are presented in Figure I-2.6-1 and Tables I-2.6-1 and I-2.6-2. Predicted thrust compensator loads and flow rates vs. axial position are shown in Figure I-3.1.2-1.

3.2 TPA HOUSING

3.2.1 Description

The design layout, displaying the general configuration of the turbopump assembly housing, is shown in Figure I-3.2.1-1.

3.2.2 Specification

The housing shall have no critical modes of vibration within ± 10% of the operating speed (667 cps) with cavities pressurized to 1.2 times design operating pressure for each cavity and input acceleration shall be 1G from 100 -1000 cps. The housing shall withstand the cavities being pressurized to 1.4 times design operating pressure while simultaneously applying a thrust load of 140,000 lbs. for three minutes with no permanent deformation along the

pump shaft axis of more than 0.020 in., or radial misalignment for the pump shaft center in excess of 0.008 in. Further, there shall be no permanent structural damage that would compromise the strength of the housing.

3.3 OXIDIZER PUMP

3.3.1 Description

The general configuration of the single-stage oxidizer pump is shown in Figure I-3.3.1-1.

3.3.2 Specification

The oxidizer main stage inducer and impeller specifications for design purposes are shown in Tables I-3.3.2-1 and I-3.3.2-2, respectively.

3.3.3 Performance

The predicted main stage pump noncavitating performance is shown in Figure I-3.3.3-1. The predicted head loss due to cavitation is shown in Figure I-3.3.3-2.

3.4 FUEL PUMP

3.4.1 Description

The fuel pump subassembly consists of a first and second-stage pump, as shown in Figure I-3.4.1-1.

3.4.2 Specification

The fuel inducer and impeller specifications for design purposes are shown in Tables I-3.3.2-1 and I-3.3.2-2, respectively.

3.4.3 Performance

The predicted fuel pump noncavitating performance is shown in Figure I-3.3.3-1 for the main stage, and Figure I-3.4.3-1 for the second stage. The predicted head loss in main stage performance due to cavitation is shown in Figure I-3.3.3-2.

3.5 TURBINE

3.5.1 Description

The turbopump drive turbine is single stage and is located between the oxidizer and fuel pumps as shown in Figure I-3.1.1-2.

3.5.2 Specification

The turbine specification for design purposes is shown in Table I-3.5.2-1.

3.5.3 Performance

The predicted turbine shaft torque parameter versus speed parameter and pressure ratio is shown in Figure I-3.5.3-1. The predicted turbine efficiency versus velocity ratio is shown in Figure I-3.5.3-2. The predicted turbine weight flow parameter versus pressure ratio and speed is shown in Figure I-3.5.3-3.

3.6 WEAR RINGS

3.6.1 Description

The wear rings are located as shown in Figure I-3.1.1-2.

3.6.2 Specification

The criterion for success shall be the demonstration of wear ring rubbing in N_2O_4 and $.5N_2H_4$-.5 UDMH with no resultant explosion. The flow and pressure drop requirements will be established so that they are acceptable to the turbopump design.

3.7 BEARINGS

3.7.1 Description

The bearings are propellant-lubricated rolling contact as shown in Figures I-3.1.1-2 and I-3.1.1-6.

3.7.2 Specification

Propellant-lubricated bearings will have the ultimate goal of operating at design loads of 40,000 rpm and a D X N value of 1.6×10^6 using N_2O_4 and $.5N_2H_4$ - .5 UDMH as the bearing coolants.

Turbopump assembly power transmission specifications are given in Tables 3.7.2-1, I-3.7.2-2 and Figure I-3.7.2-1. The bearing lubrication flow rates are given in Figure I-3.1.1-6 and the allowable bearing misalignment is presented in Figure I-3.7.2-2.

3.8 HYDROSTATIC COMBUSTION SEAL

3.8.1 Description

The hydrostatic combustion seal is shown in Figure I-3.8.1-1. It consists of a nonrotating sealing face which operates in close proximity to a rotating face on the shaft.

3.8.2 Specification

Fuel from the pump discharge is supplied, through orifices, into pockets recessed into the nonrotating face. Operating clearance of .001 inch is controlled by the fuel flow into the pockets. The use of separate pockets provides the stationary face with a strong hydrostatic force which compensates for axial deflections in the rotating face.

The seal design operating conditions are as follows:

Speed	40,000 rpm
Pressure	3,100 ± 600 psia
Temperature	1100° ± 50°F

Table I-3.3.2-1

ARBS MAIN STAGE
INDUCER DESIGN
SPECIFICATION (u)

	HYDRAULIC DESIGN PT	MAXIMUM STRESS CONDITION
Temperature - °F	77	77
Density - lb/ft^3		
γ_{OSMI}	89.5	89.5
γ_{FSMI}	56.1	56.1
Vapor Pressure - lb/in^2		
P_{OVMI}	18.0	-
P_{fVMI}	2.8	-
Speed - RPM	40,000	44,000
Head Rise - FT		
H_{ODMI}	1660	2010
H_{fDMI}	1360	1645
Flow Rate - GPM		
Q_{OSMI}	1444	1590
Q_{fSMI}	945	1040
Efficiency - % (Minimum)		
η_{OMI}	70	
η_{fMI}	70	
Net Positive Suction Head - FT		
$NPSH_{OSMI}$	200	
$NPSH_{FSMI}$	140	
Shaft Horsepower - HP		
HP_{OMI}	-	1670
HP_{fMI}		575
Inducer Discharge Pressure - PSIA		
P_{ODMI}	1290	1560
P_{fDMI}	685	830

Table I-3.3.2-2

ARES MAIN STAGE IMPELLER
DESIGN SPECIFICATION (u)

	Hydraulic Design Pt.	Maximum Stress Condition
Temperature, °F	77	77
Specific Weight, lb/ft^3		
γ_{OSM}	89.5	89.5
γ_{FSM-1}	56.1	56.1
Vapor Pressure, $lb/in.^2$		
P_{OVM}	18.0	-
P_{FVM-1}	2.8	-
Speed, rpm	40,000	44,000
Head Rise, ft		
H_{ODM}	7,990	9,660
H_{FDM-1}	8,175	9,900
H_{FDM-2}	6,150	7,450
Flow Rate, gpm		
Q_{OSM}	*1,597	1,755
Q_{FSM-1}	*1,170	1,290
Q_{FSM-2}	173	190
Efficiency, % (minimum)		
η_{OM}	74	
η_{FM-1}	66	
η_{FM-2}	57	
NPSH, ft (minimum)		
$NPSH_{OSM}$	1,860	
$NPSH_{FSM-1}$	1,540	
Shaft Power, hp		
SHP_{OM}		7,600
SHP_{FM-1}		3,300
SHP_{FM-2}		485
Pump Discharge Pressure, psia		
P_{ODM}	6,000	7,300
P_{FDM-1}	3,750	4,500
P_{FDM-2}	5,750	7,000

*Includes wear ring leakage and bearing coolant flows (see Figure 3.1.1-5

Table I-3.5.2-1

ARES MAIN STAGE TURBINE
DESIGN SPECIFICATION (u)

	Aerodynamic Design Pt.	Maximum Stress Conditions
Shaft Power - HP	10,070	13,450
Gas Flow Rate - lb/sec	233.3	
Gas Inlet Total Pres.-psia	4,650	5,630
Gas Static Exit Pressure-psia	3,100	
Gas Inlet Total Temperature - °F	1,240	1,400
Shaft Speed - RPM	40,000	44,000
Efficiency - % (Minimum)	77	
Specific Heat Ratio, γ	1.257	
Gas Constant R-Ft/°R	46.62	
M.R. - N_2O_4/.5 N_2H_4 + .5 UDMH	11.30	

Table I-3.7.2-1

ARES POWER TRANSMISSION

DESIGN SPECIFICATION (u)

	NOMINAL OPERATING POINT	MAXIMUM STRESS CONDITIONS
1. Shaft speed, rpm	40,000	44,000
2. Shaft torque, ft-lb		
T_o, Oxidizer Pump	907	1,100
T_{f_1}, 1st Stg Fuel Pump	366	445
T_{f_2}, 2nd Stg Fuel Pump	50	61
3. Coolant Temp - °F	77	77
4. Coolant properties: @ 77°F		
Specific heat		
N_2O_4	.37	.37
.5 N_2O_4 + .5 UDMH	.69	.69
Density - lb/ft^3		
ρ_o	89.5	89.5
ρ_f	56.1	56.1
5. Minimum Critical Speed, rpm		48,000
6. Vehicle vertical acceleration - ft/sec^2		10 g's
Acceleration, perpendicular to thrust axis - ft/sec^2		5 g's
7. Maximum TPA angular acceleration rpm/sec		80,000

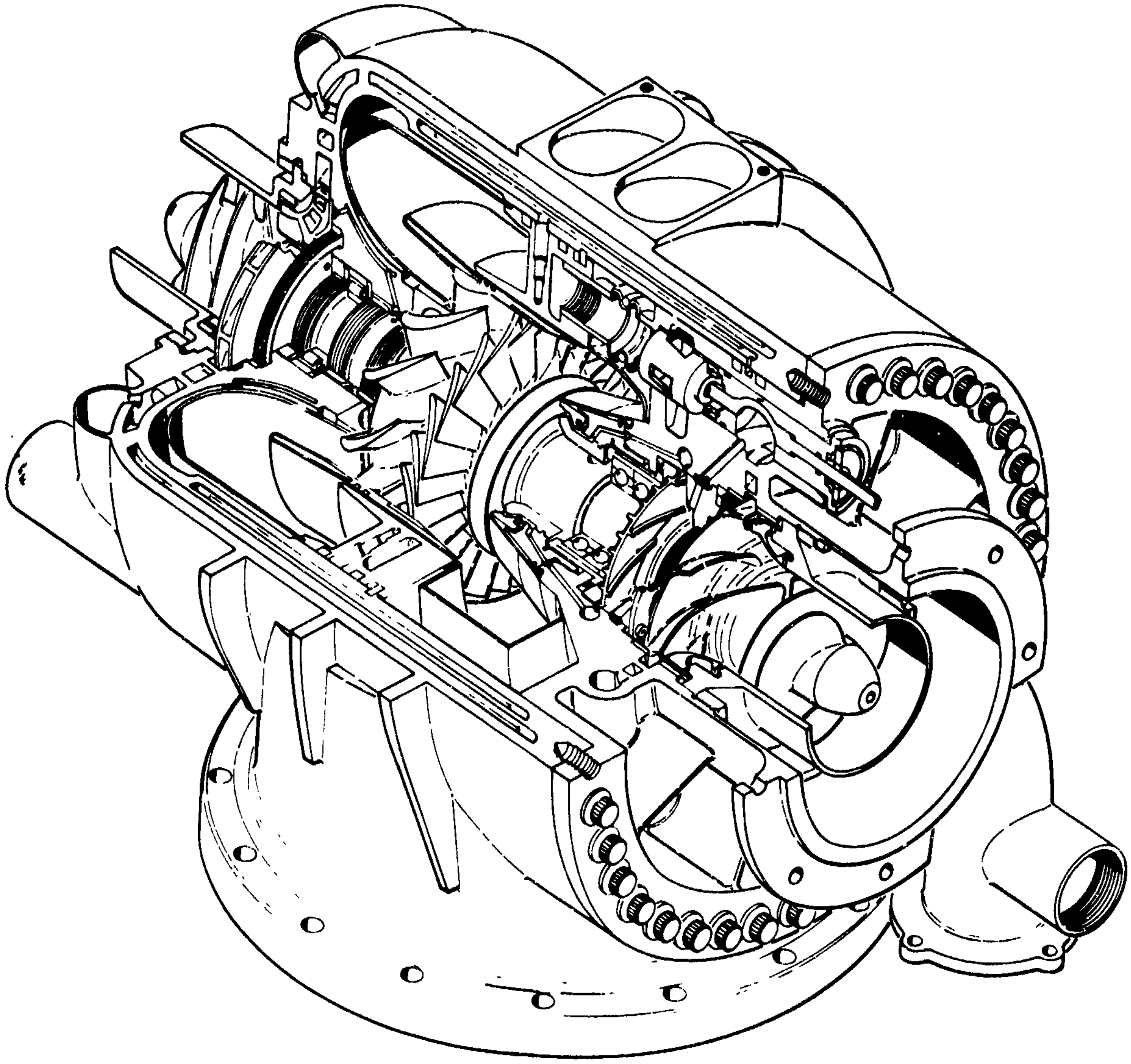
8. Maximum steady state bearing loads, component weights, and Polar moments of Inertia. (Ref. attached Drawing #1)

Table I-3.7.2-2

ARES BEARINGS
DESIGN SPECIFICATION

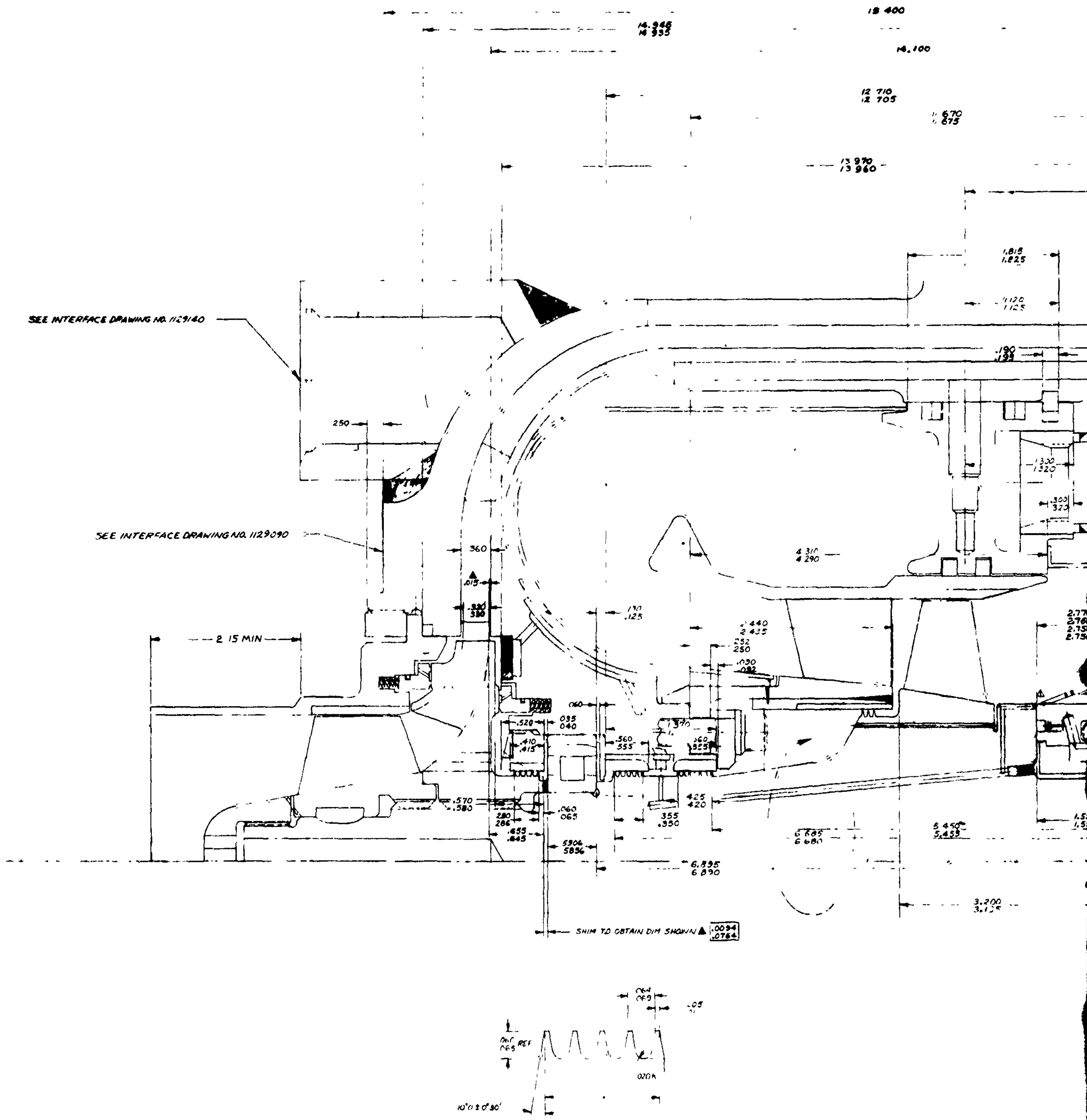
1. Bearing size (series 108) — 40 mm Bore
2. Bearing life, minimum hr
   a. Roller (ea) — 10
   b. Ball (duplex set) — 10
3. Lubrication, flow rates
   (Ref Figure 3.1.1-6)
4. Bearing coolant temp (°F) rise (approx) — 20°/brg
5. Misalignment or movement allowable
   (Ref Figure 3.7.2-2)
6. Maximum steady-state bearing loads, lb:

	Steady Stage	Transient
Ball Set	50	± 1000
Roller	500	1000

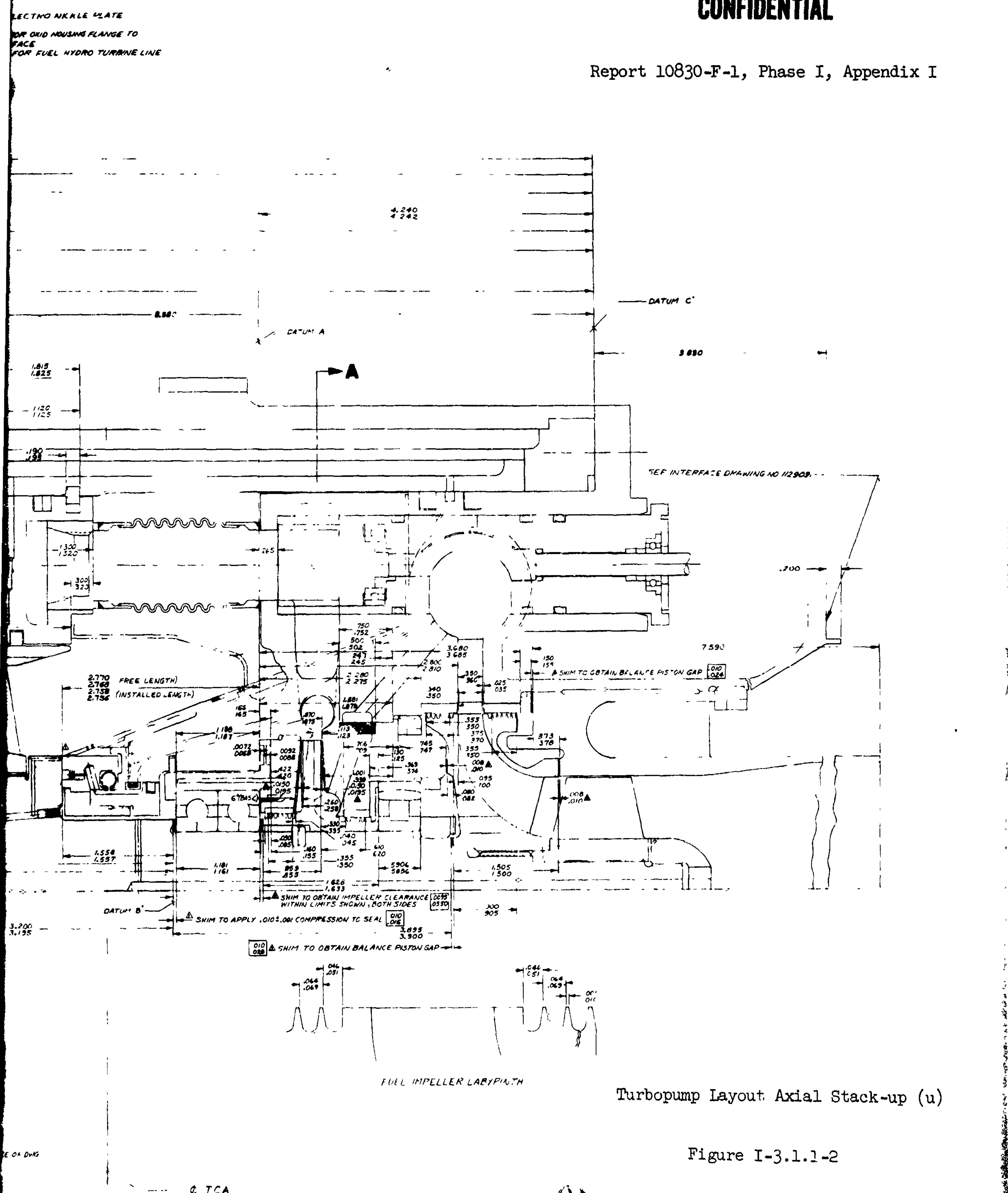


ARES Advanced Turbopump
Isometric Cutaway View (u)

NOTES 1 MODIFY THREADS TO ALLOW FOR ELECTRONICKLE ... ON ALL NUTS
2 SEE INTERFACE DRAWING NO 1128984 FOR OXID HOUSING FLA... SECONDARY INJECTOR FLANGE INTERFACE
3 SEE INTERFACE DRAWING NO 1129141 FOR FUEL HYDRO TU... INTERFACE

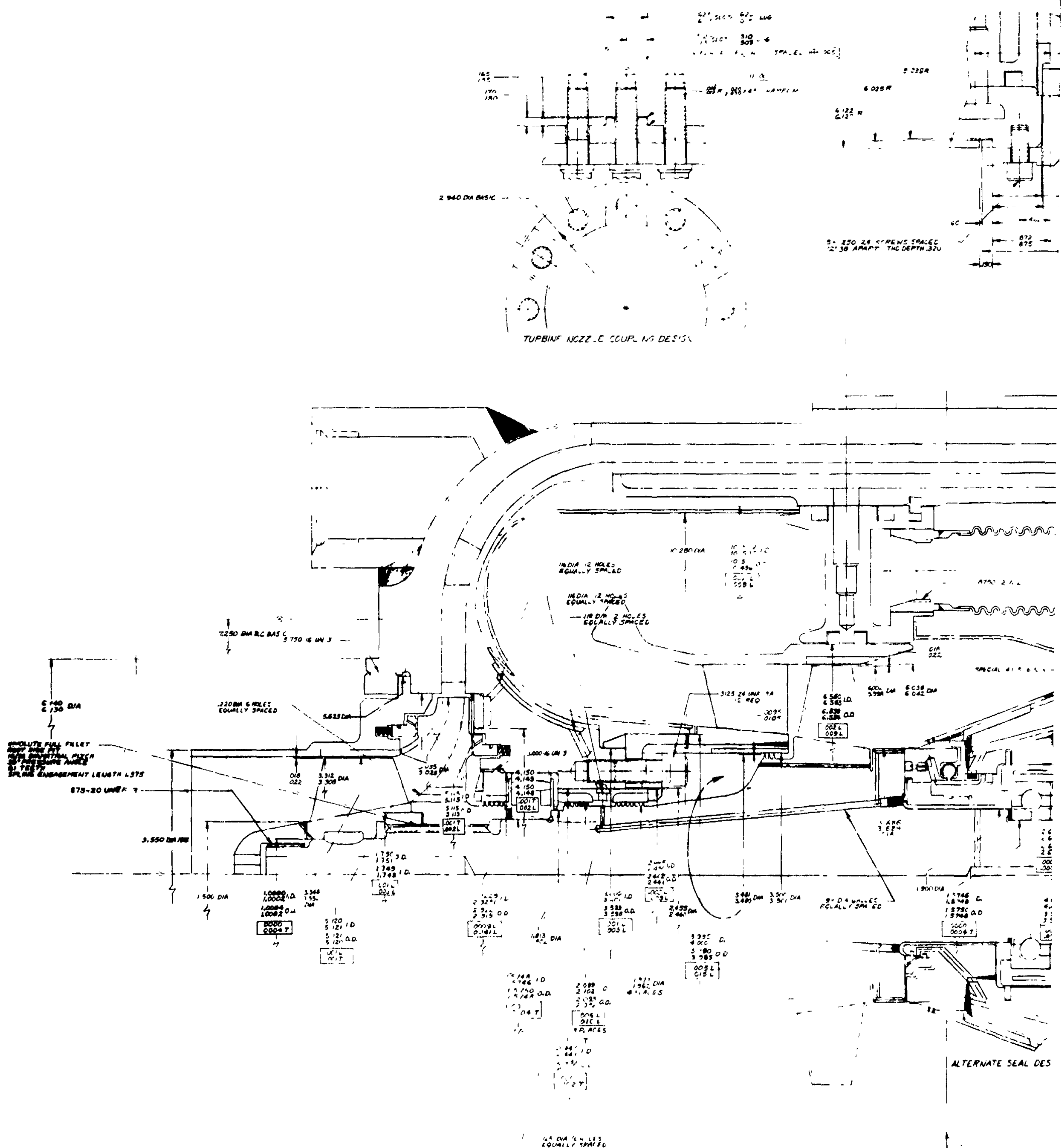


10 March 1967

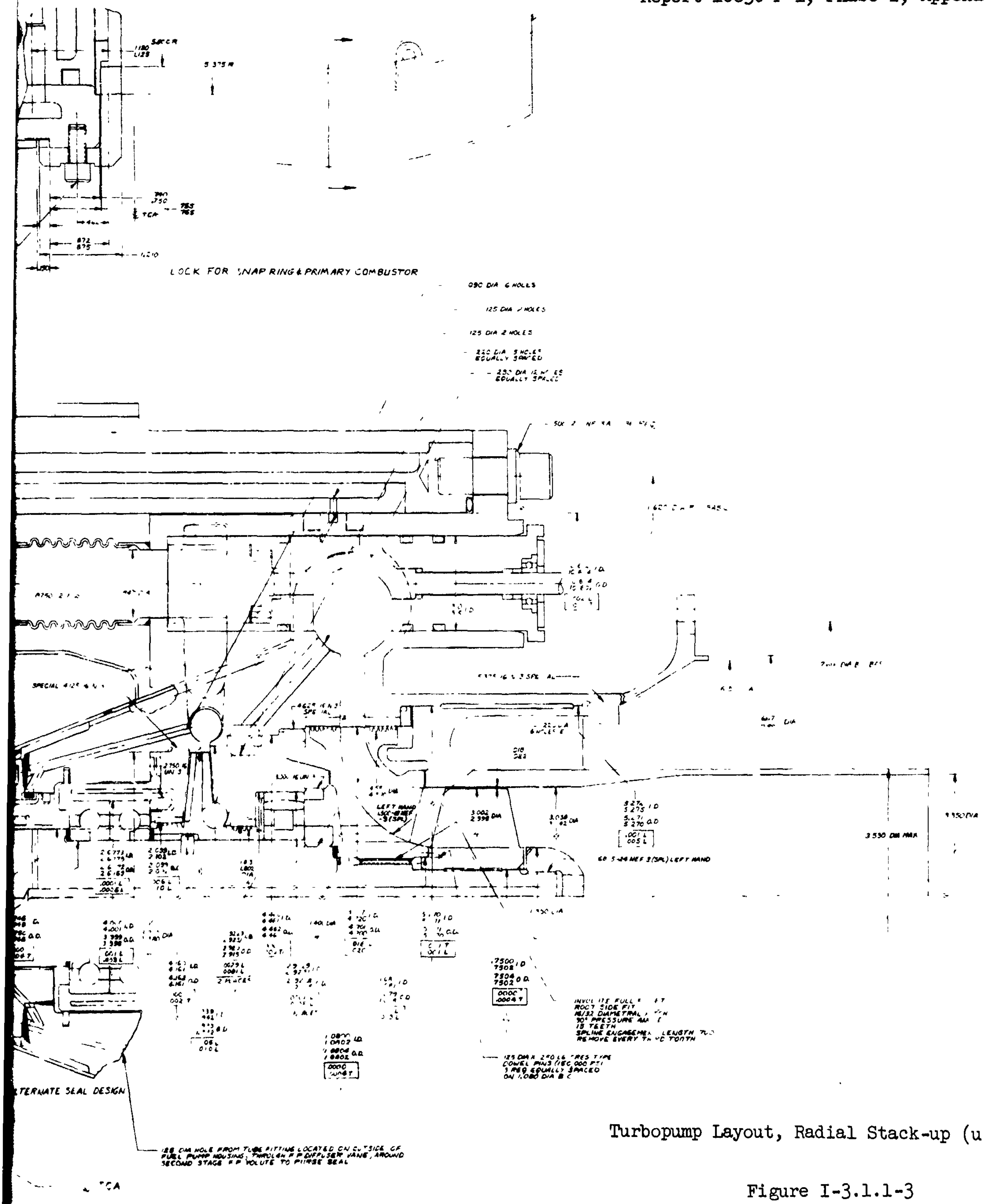


Turbopump Layout Axial Stack-up (u)

Figure I-3.1.1-2

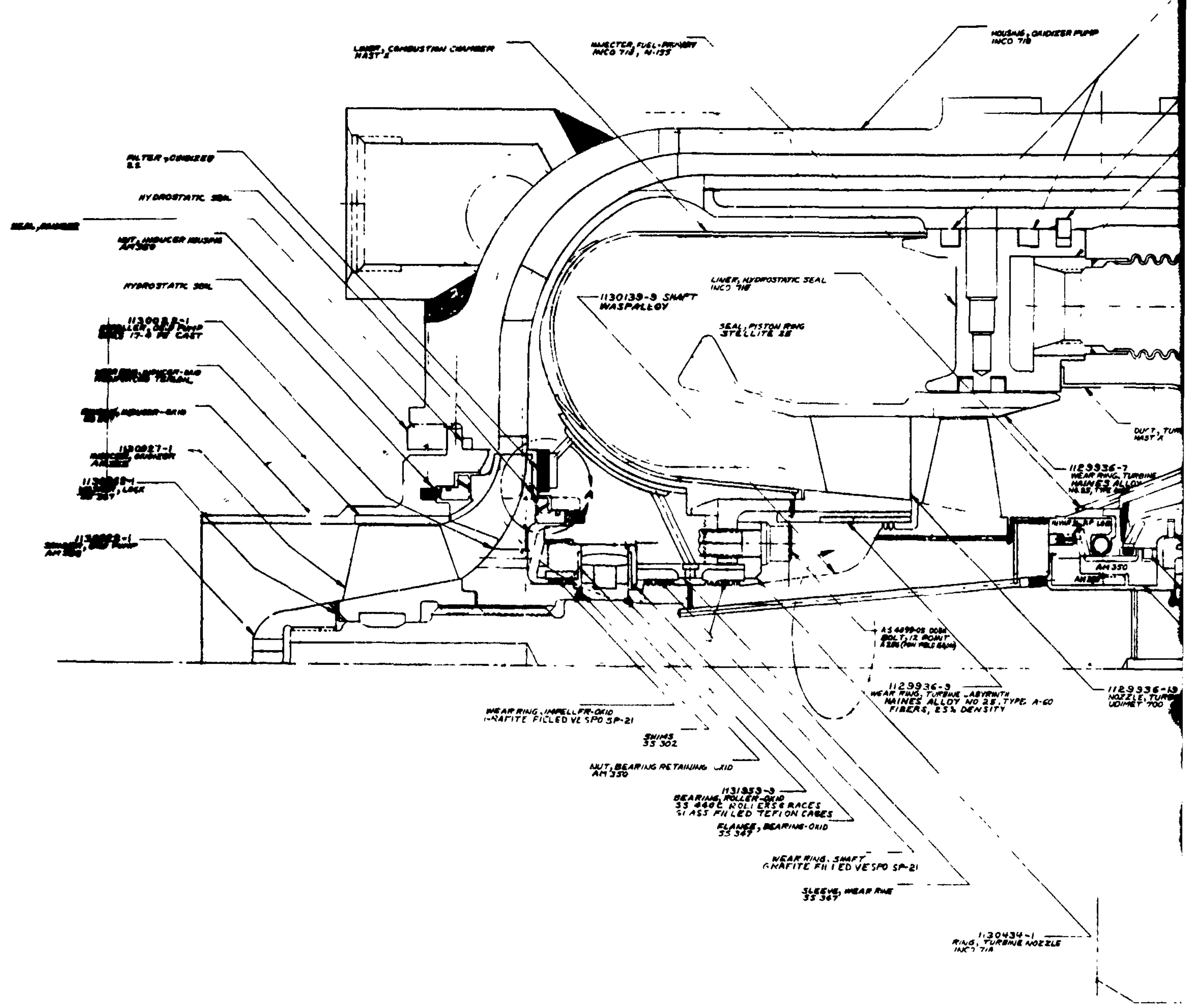


10 March 1967

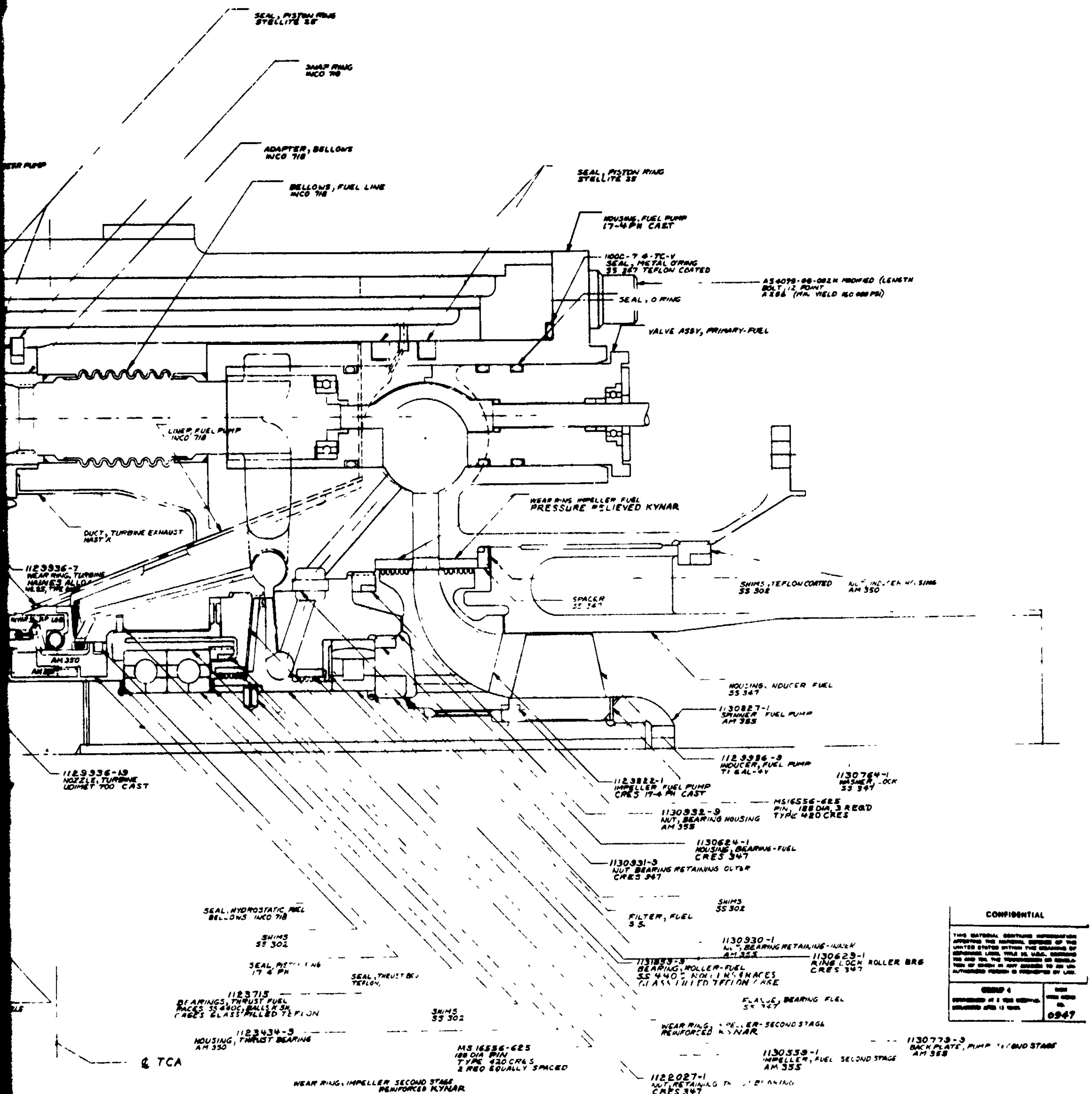


Turbopump Layout, Radial Stack-up (u)

Figure I-3.1.1-3

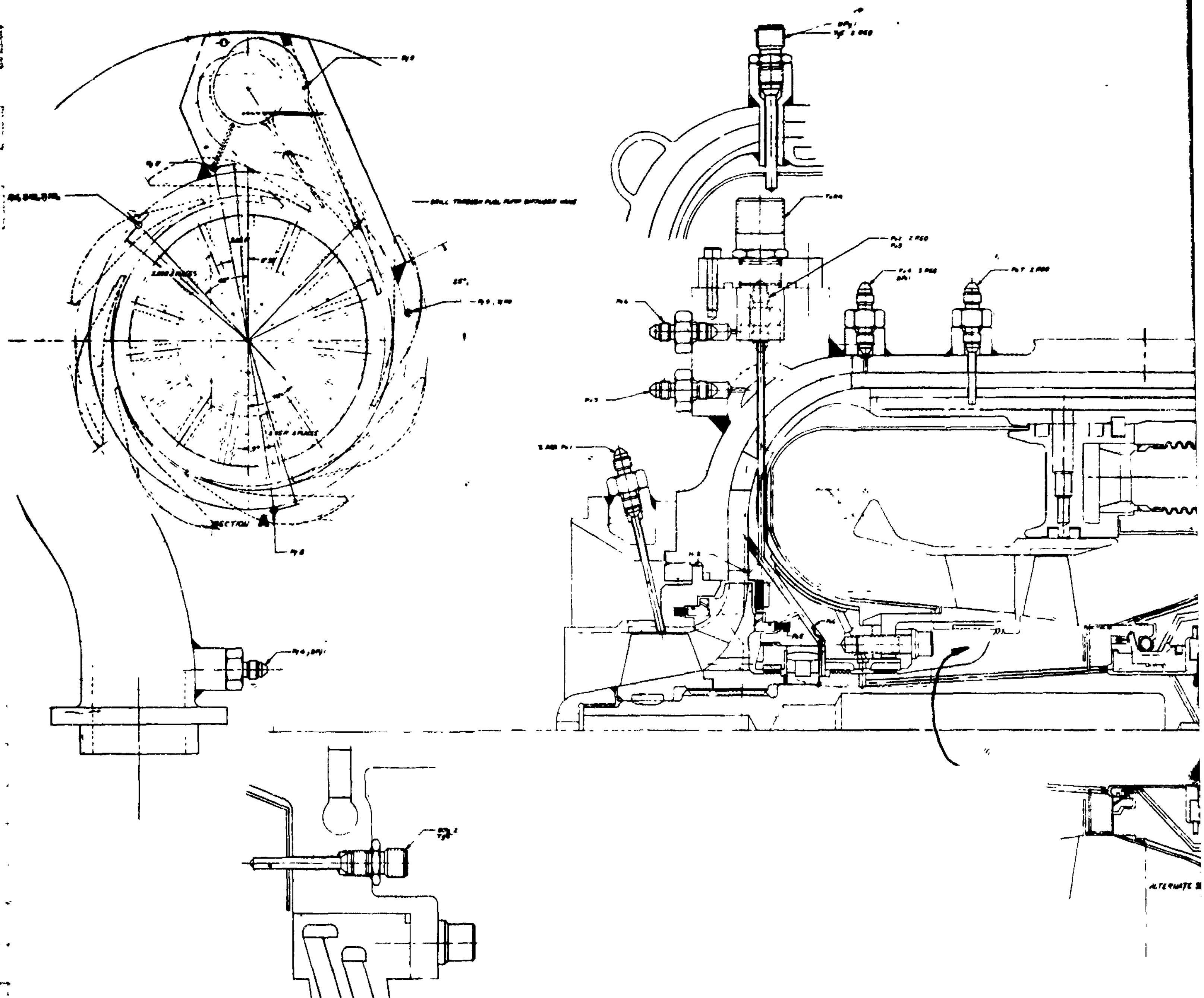


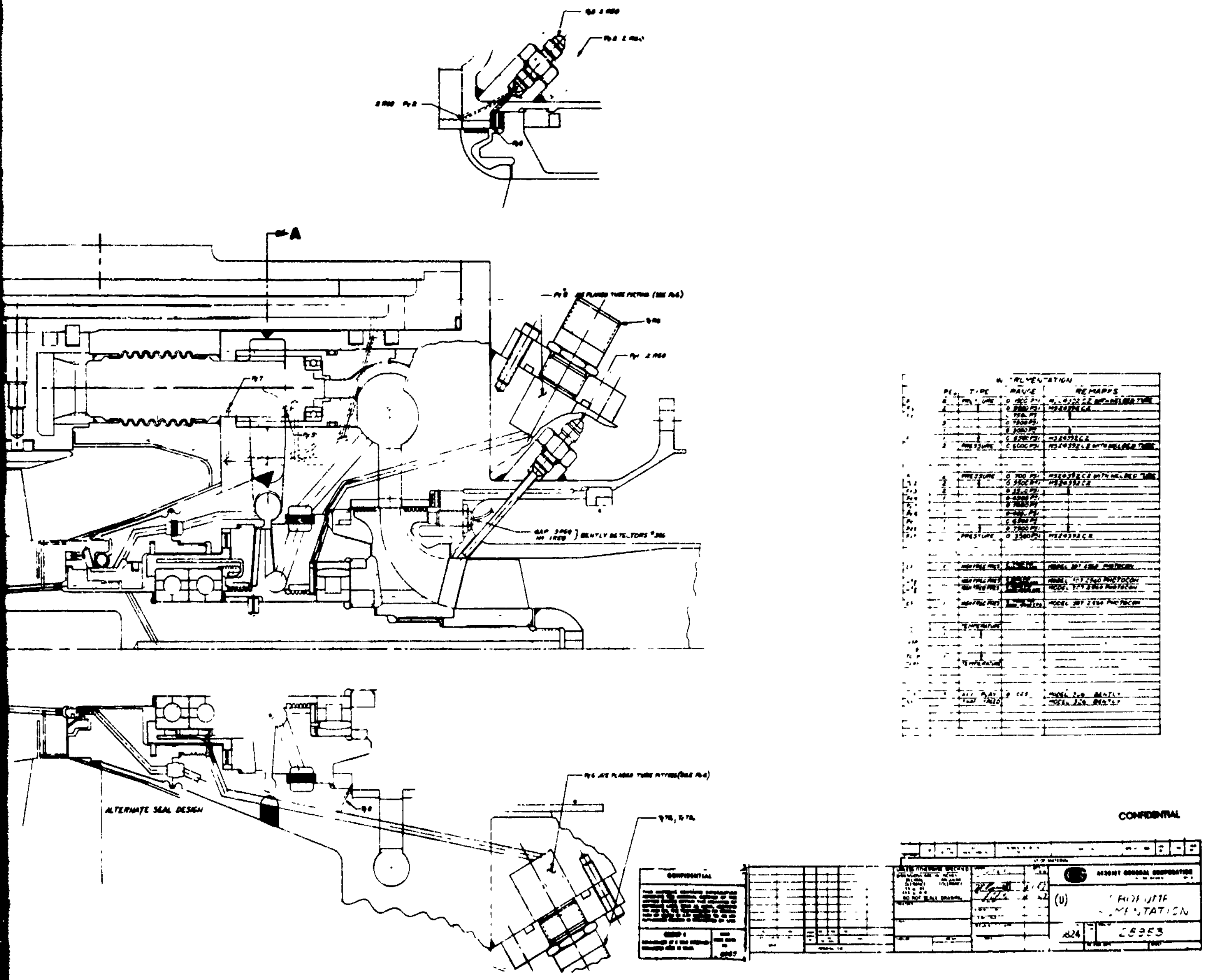
10 March 1967



Turbopump Layout Parts List and Material (u)

Figure I-3.1.1-4

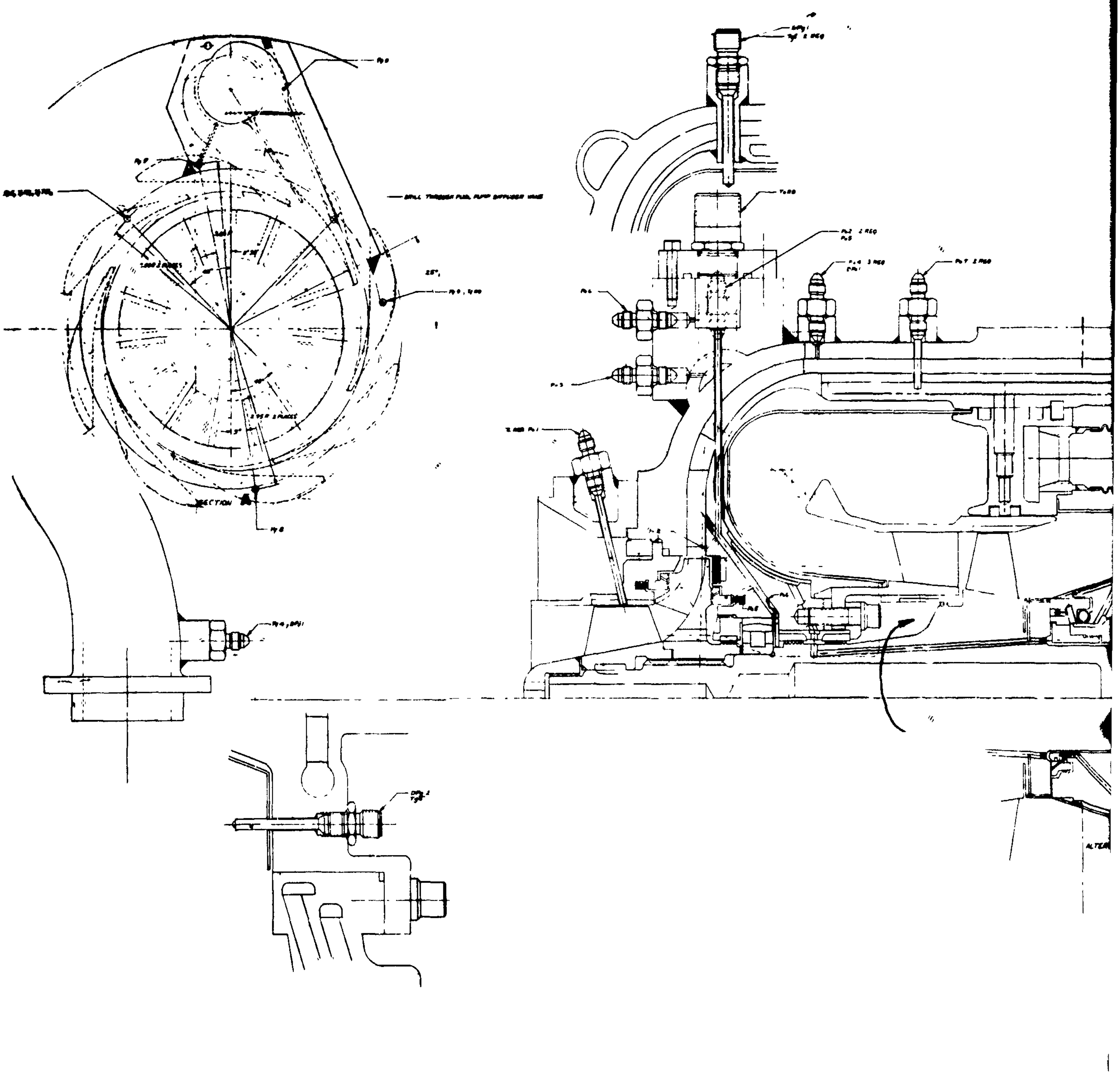


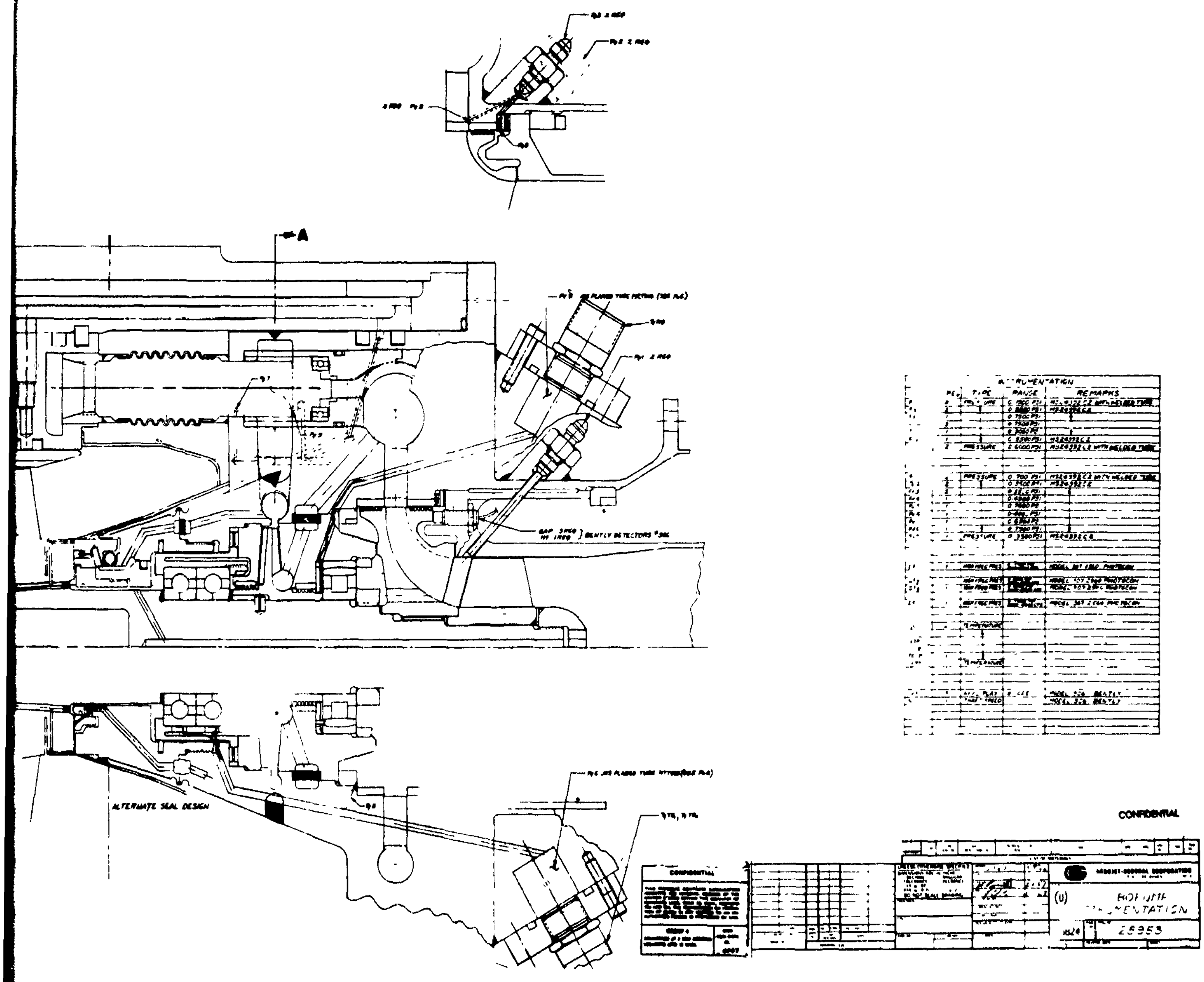


Turbopump Instrumentation (u)

Figure I-3.1.1-5

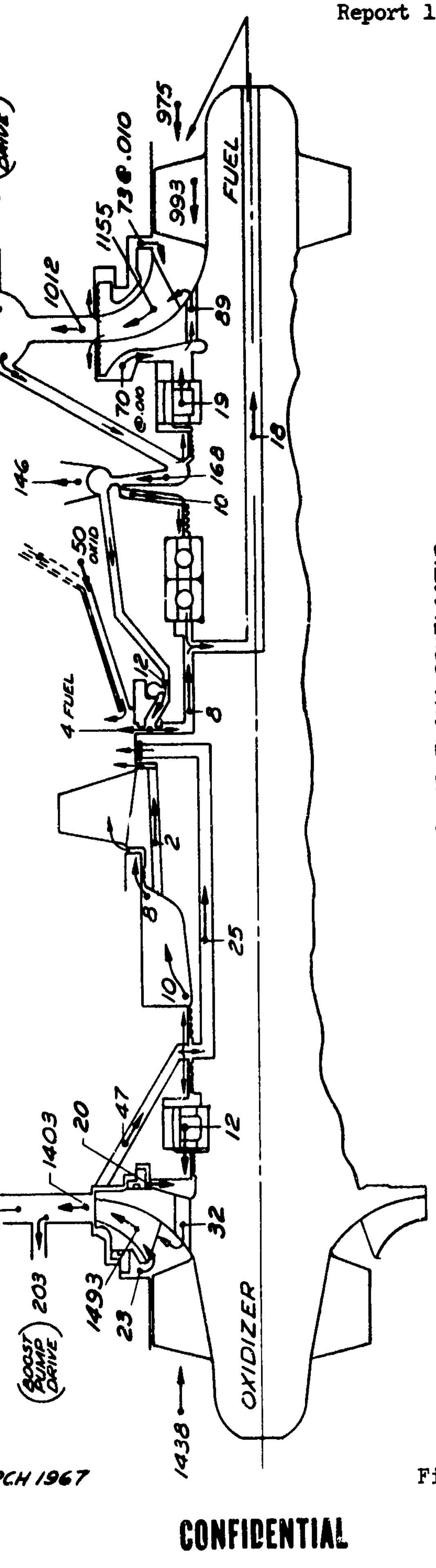
10 MARCH 1967


DRILL THROUGH FUEL PUMP DIFFUSER VANE
SECTION



Turbopump Instrumentation (u)

Figure I-3.1.1-5



NOTE: ALL FLOW VALUES SHOWN INDICATE GPM

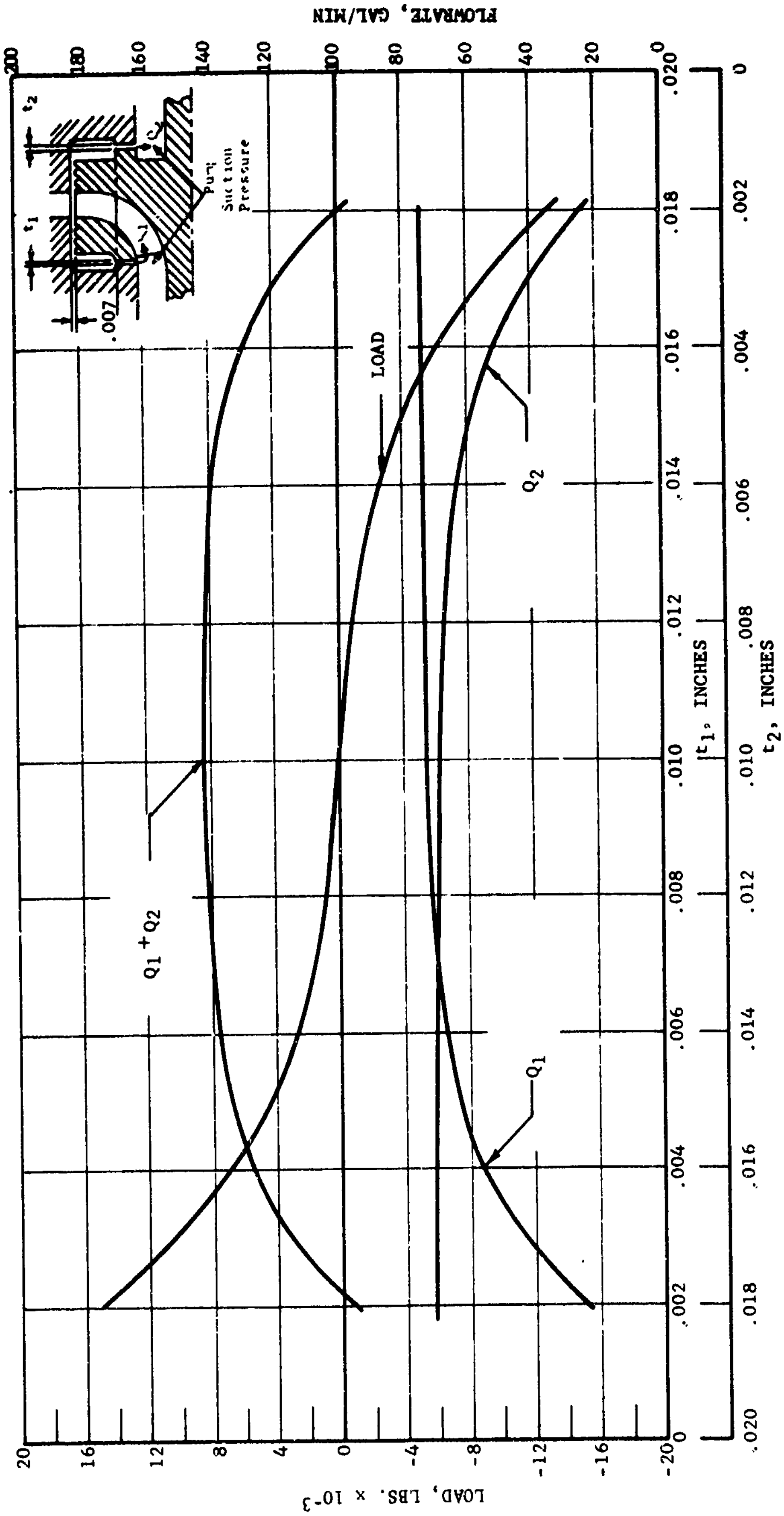
TURBOPUMP FLOW SCHEMATIC WITH TYPICAL MODULE FLOWS (U)

10 MARCH 1967

Figure I-3.1.1-6

ADVANCED TPA DESIGN

THRUST BALANCER LOAD & FLOWRATE VS AXIAL POSITION



NOTE: $t_1 + t_2 = 0.020$ IN.

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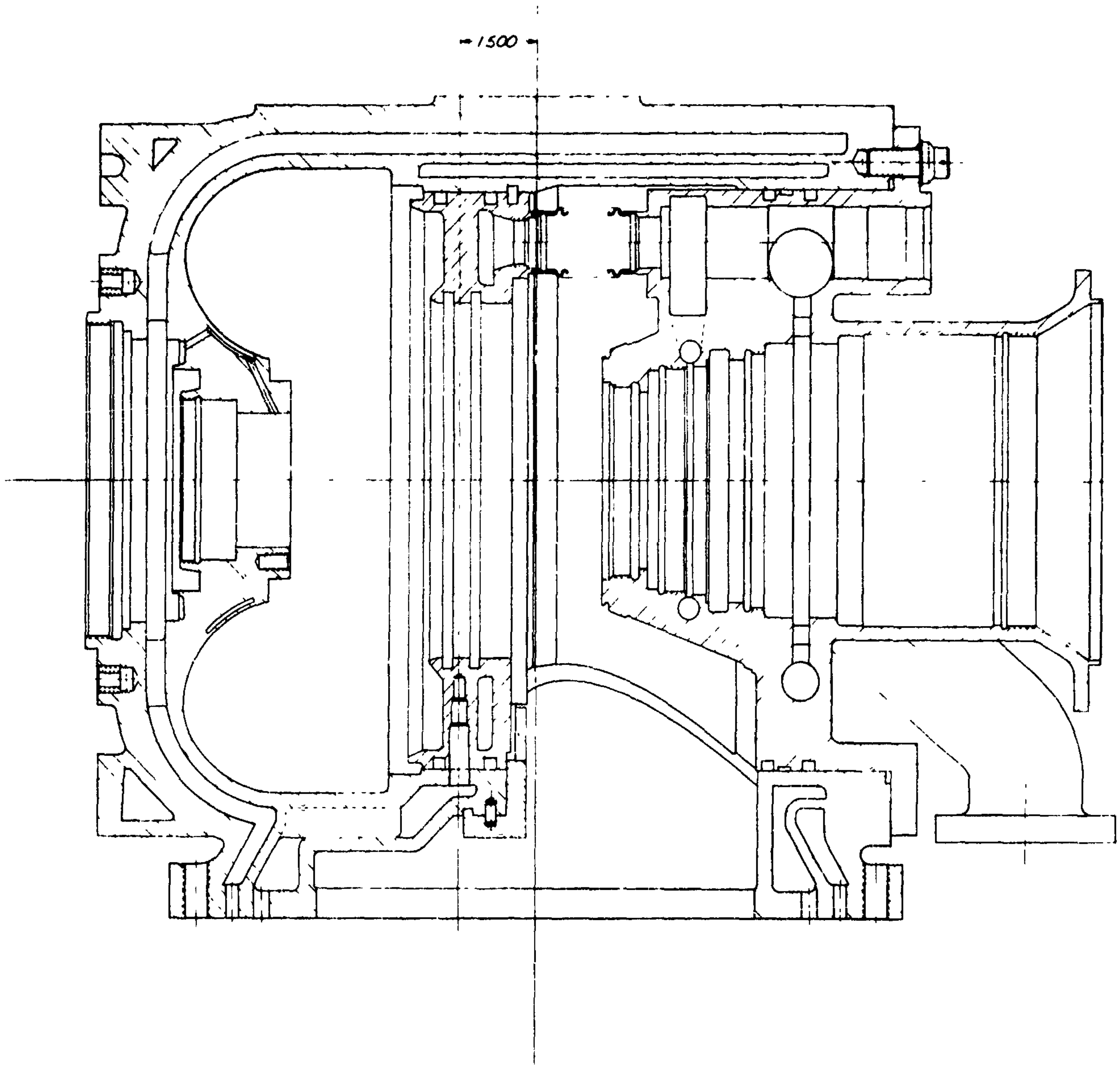
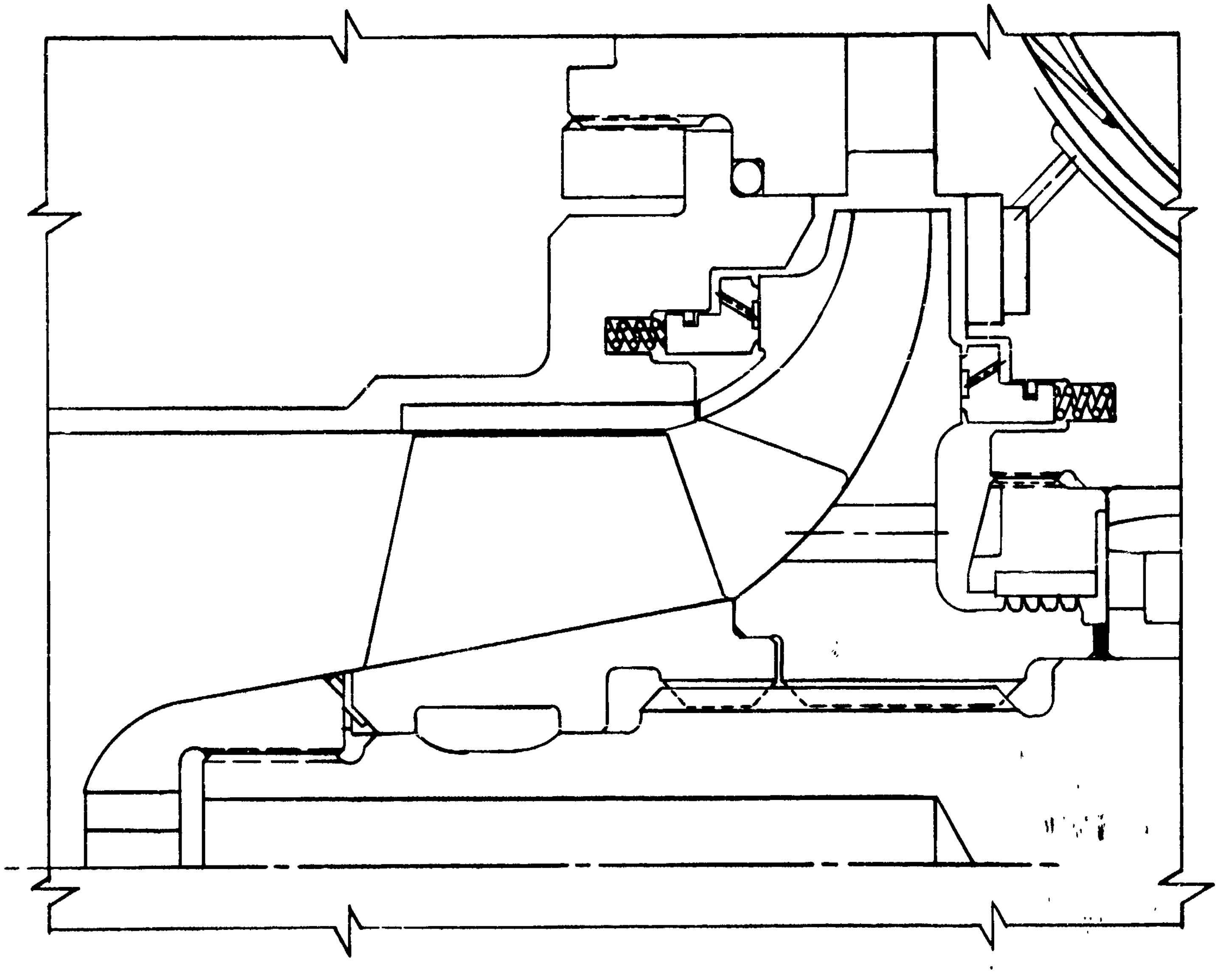


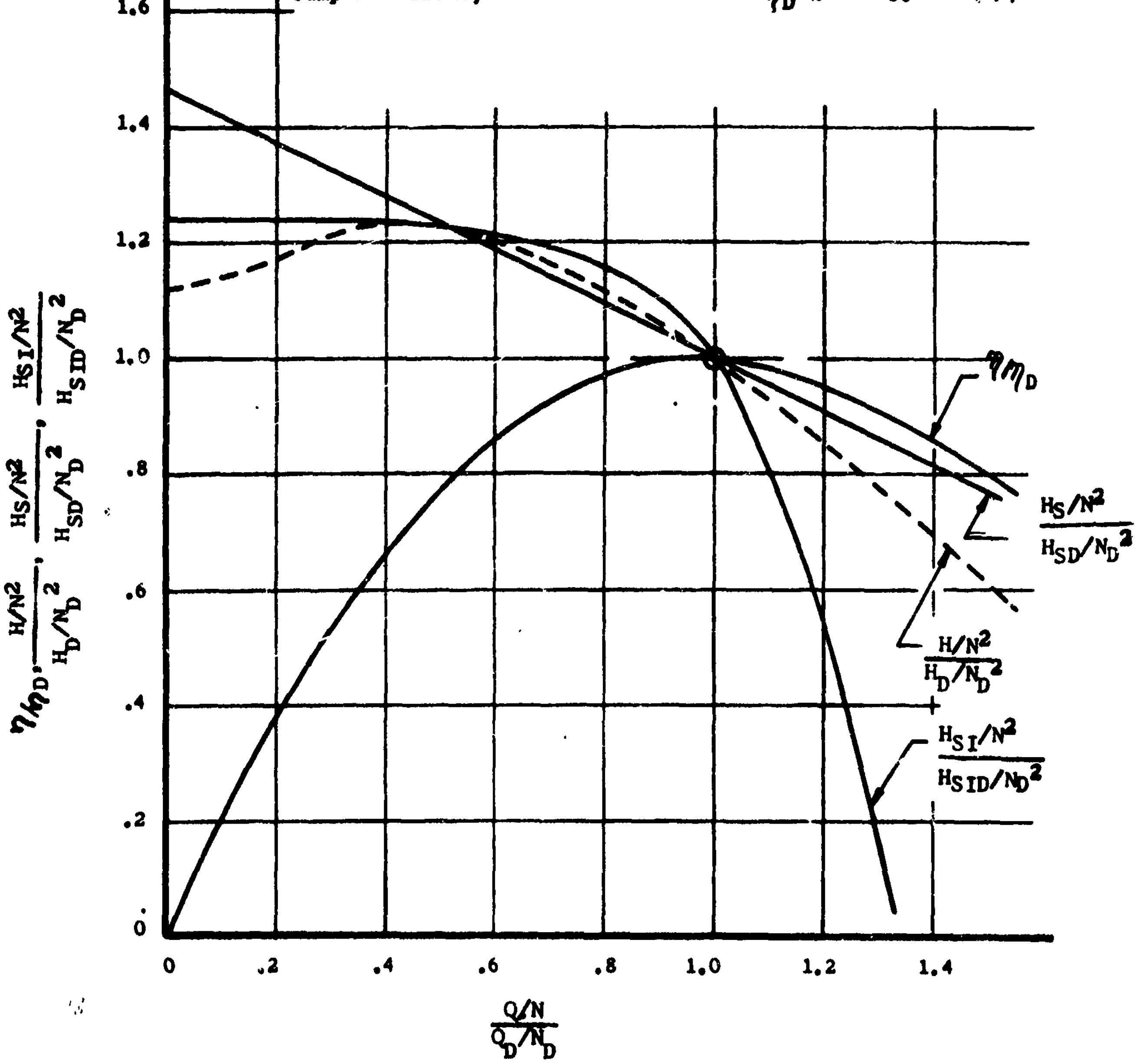
Turbopump Housing



Oxidizer Pump

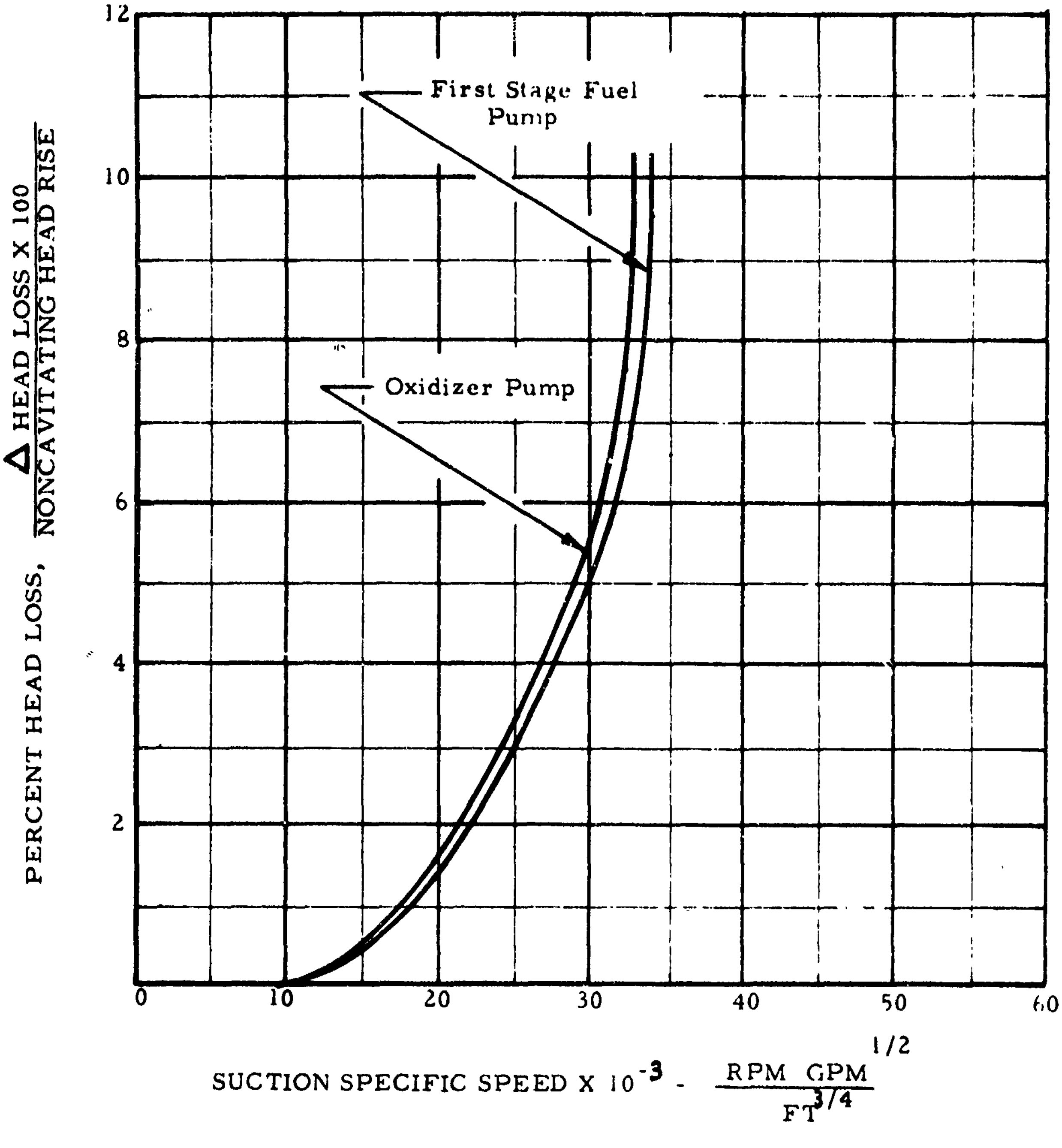
○ **DESIGN OPERATING POINT**

		FUEL	OXID
Pump flow	Q_D-GPM	945	1444
Total Head Rise	H_D-FT	9535	9650
Inducer & Impeller Static Head Rise	H_{SD}-FT	7400	8015
Inducer Static Head Rise	H_{SID}-FT	1044	1262
Pump Speed	N_D-RPM	40,000	40,000
Pump Efficiency	η_D-%	66	74

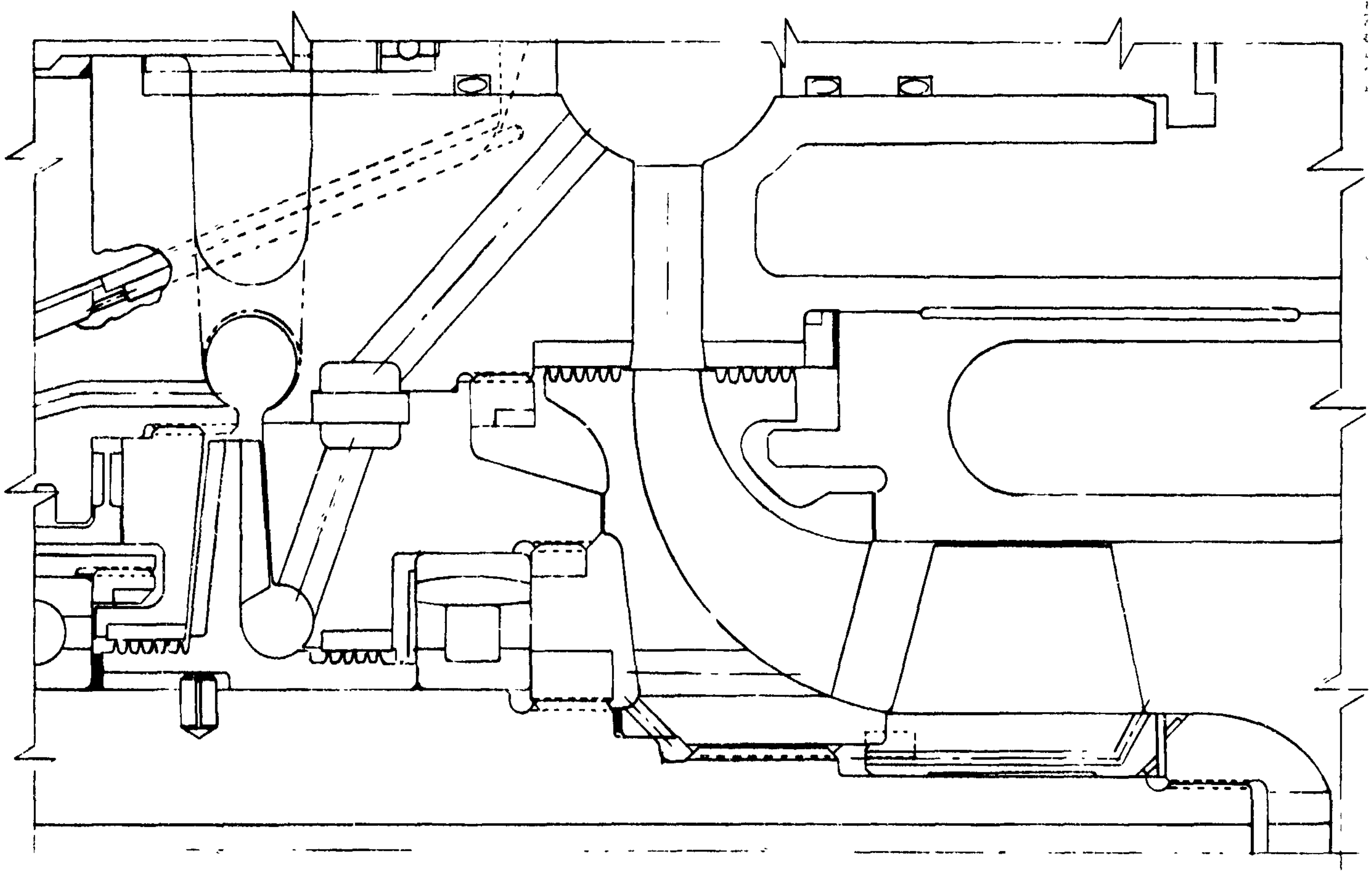


Predicted Noncavitating Performance, Oxidizer and Fuel Main-stage Pumps(u)

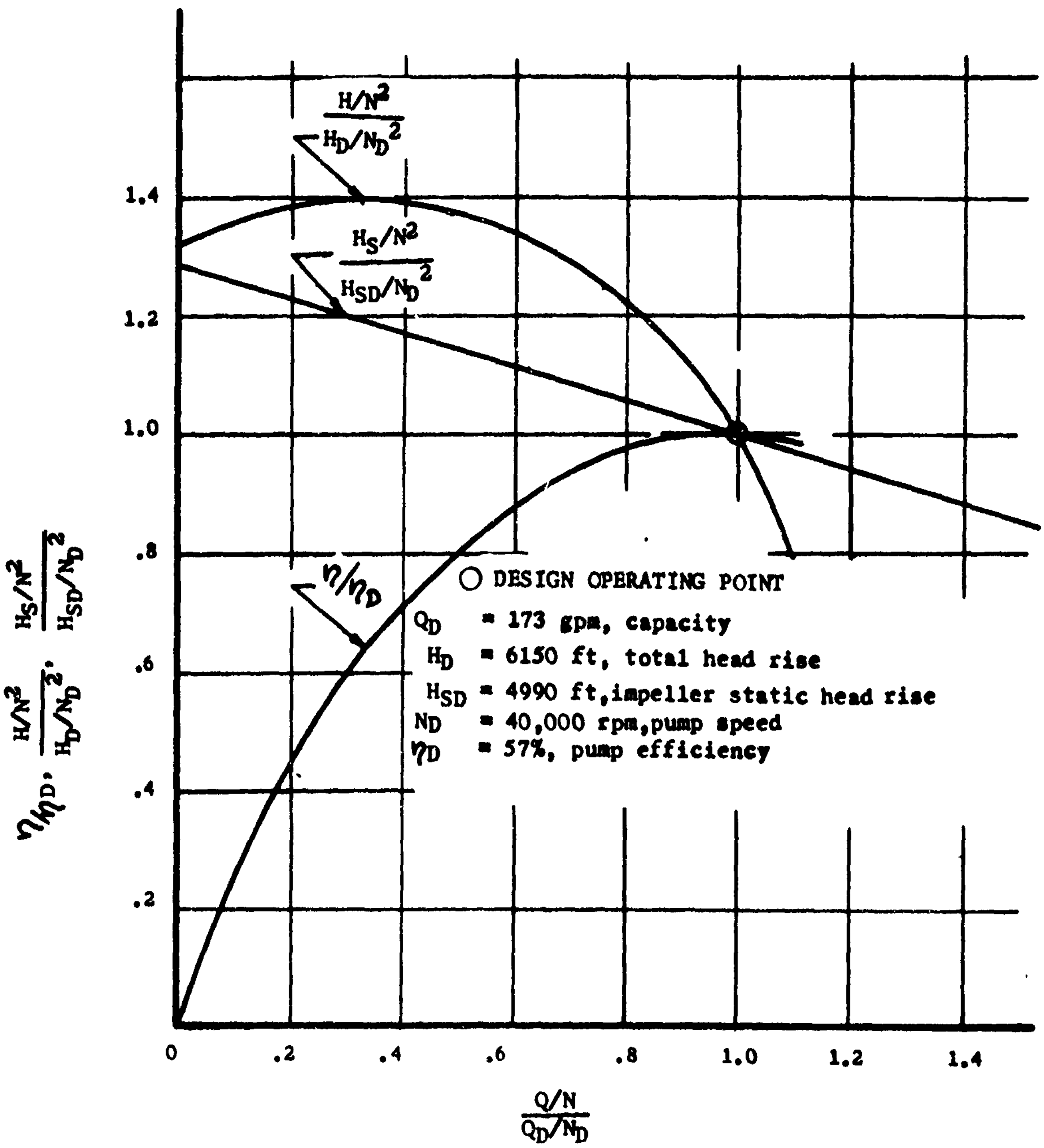
Figure I-3.3.3-1



Predicted Cavitating Head Loss Oxidizer and Fuel Main Stage Pumps



Fuel Pump



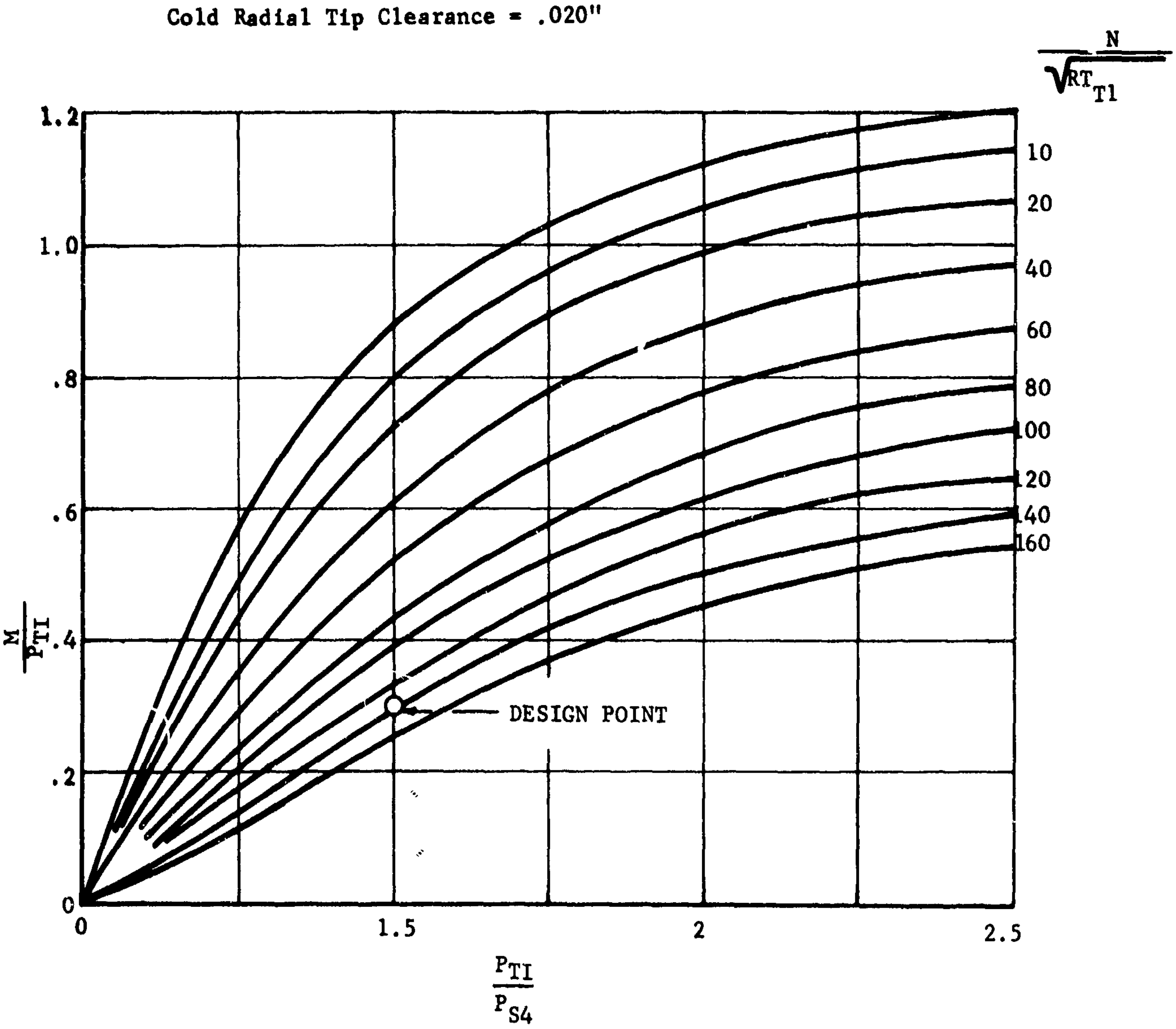
Predicted Noncavitating Performance, Second-Stage Fuel Pump(u)

Figure I-3.4.3-1

M	Torque ft-lb
T_{TI}	Inlet Total Temperature ^{o}R
P_{TI}	Inlet Total Pressure psia
P_{S4}	Outlet Static Pressure psia
N	Rotational Speed, rpm
R	Gas Constant ft/^{o}R

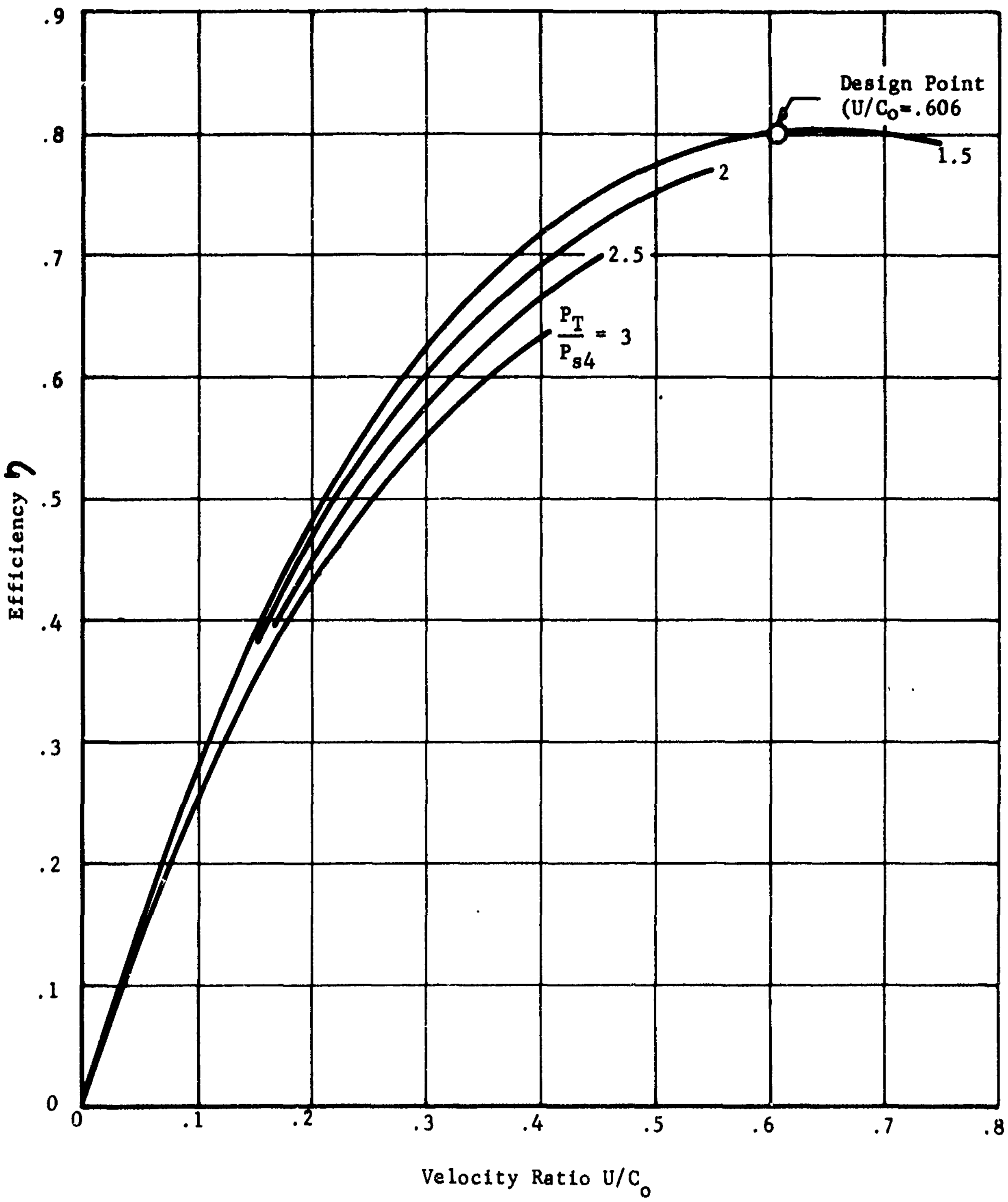
γ = 1.2572

Cold Radial Tip Clearance = .020"



PREDICTED TURBINE TORQUE vs PRESSURE RATIO AND SPEED

Figure I-3.5.3-1



Predicted Turbine Efficiency vs Pressure Ratio and Speed

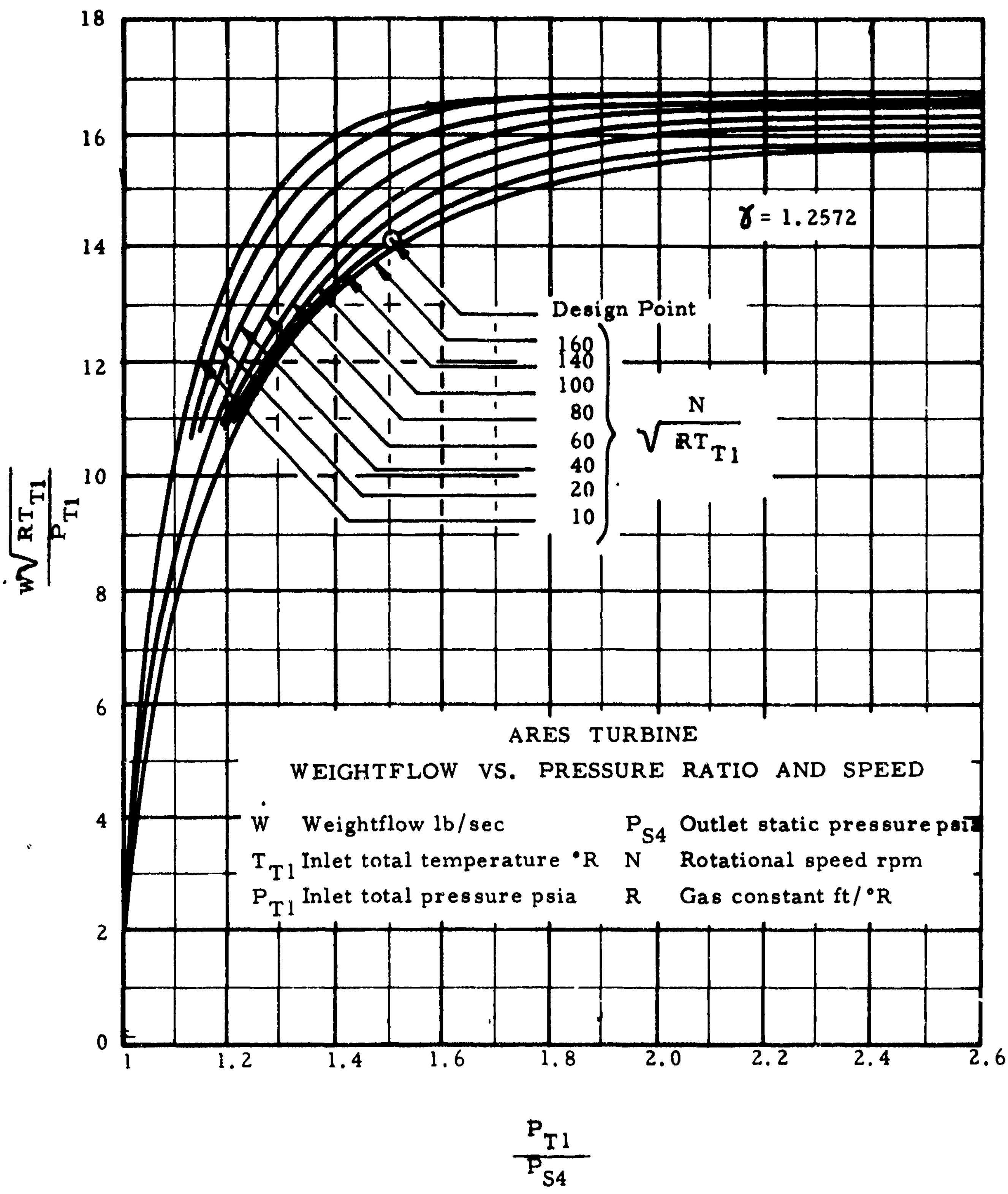
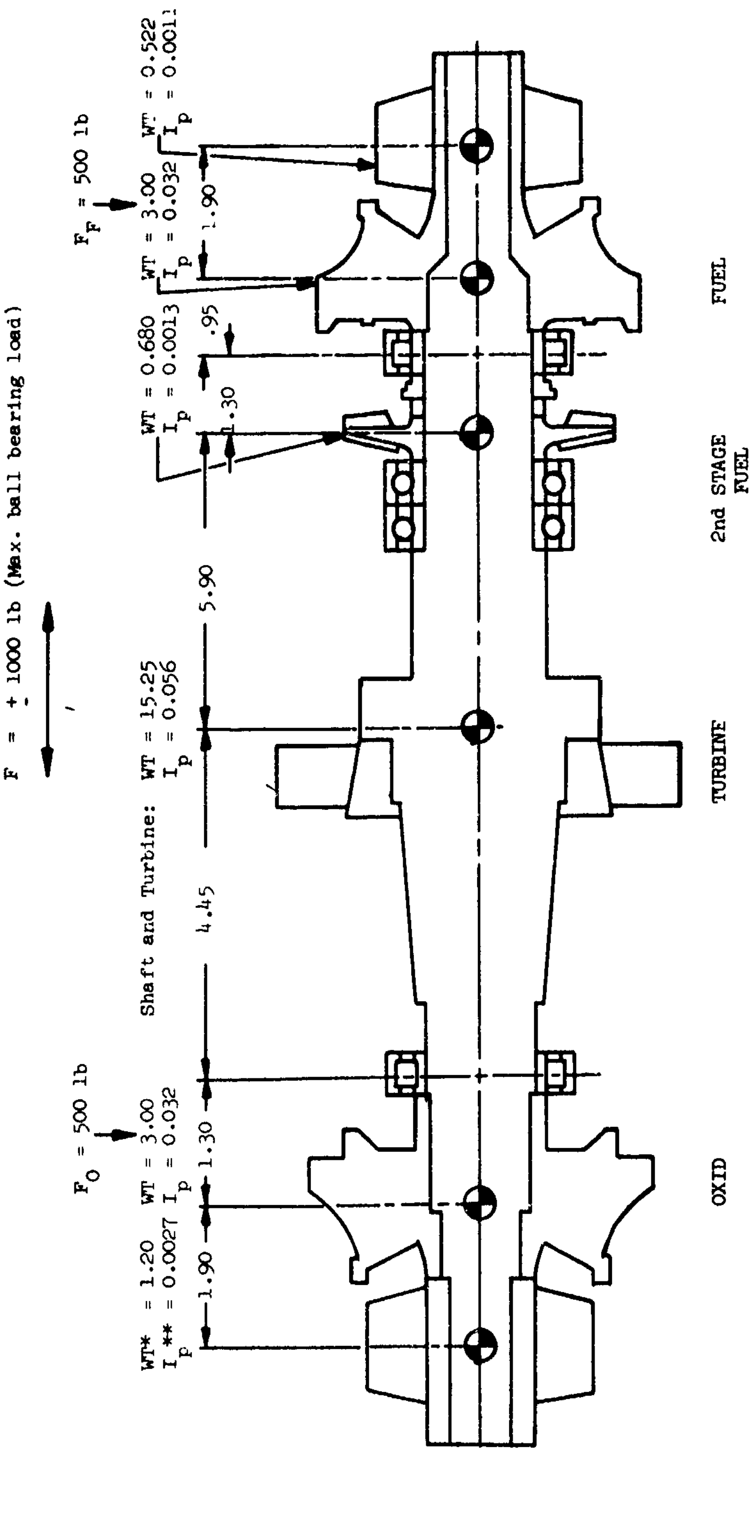


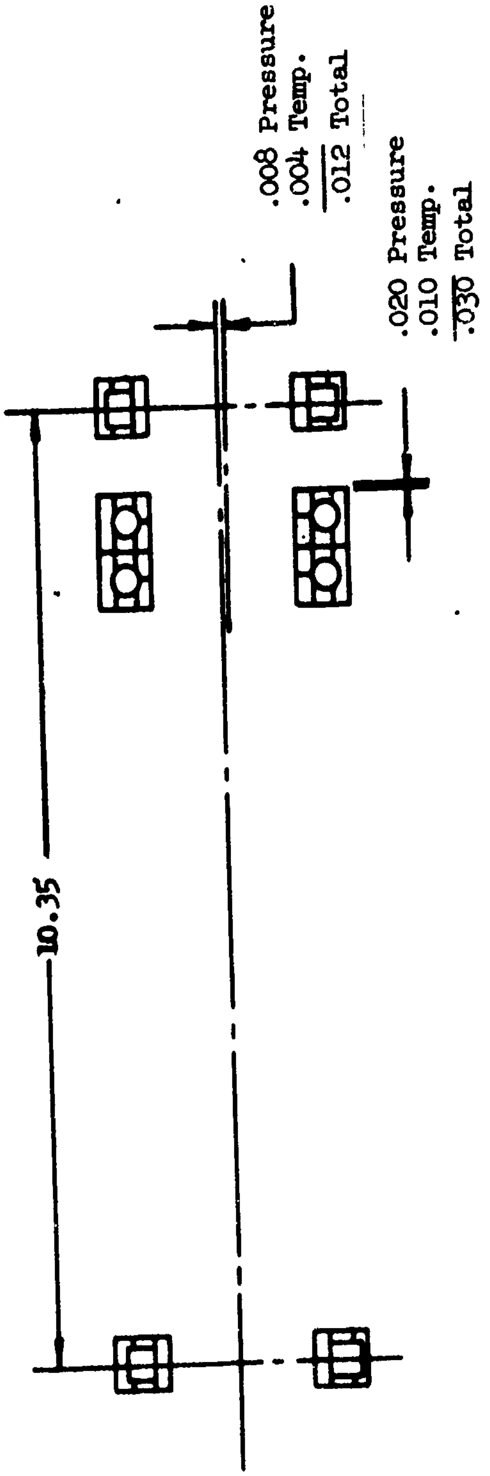
Figure I-3.5.3-3



ARES BEARING LOADS

COMPONENT WEIGHTS & POLAR MOMENTS OF INERTIA

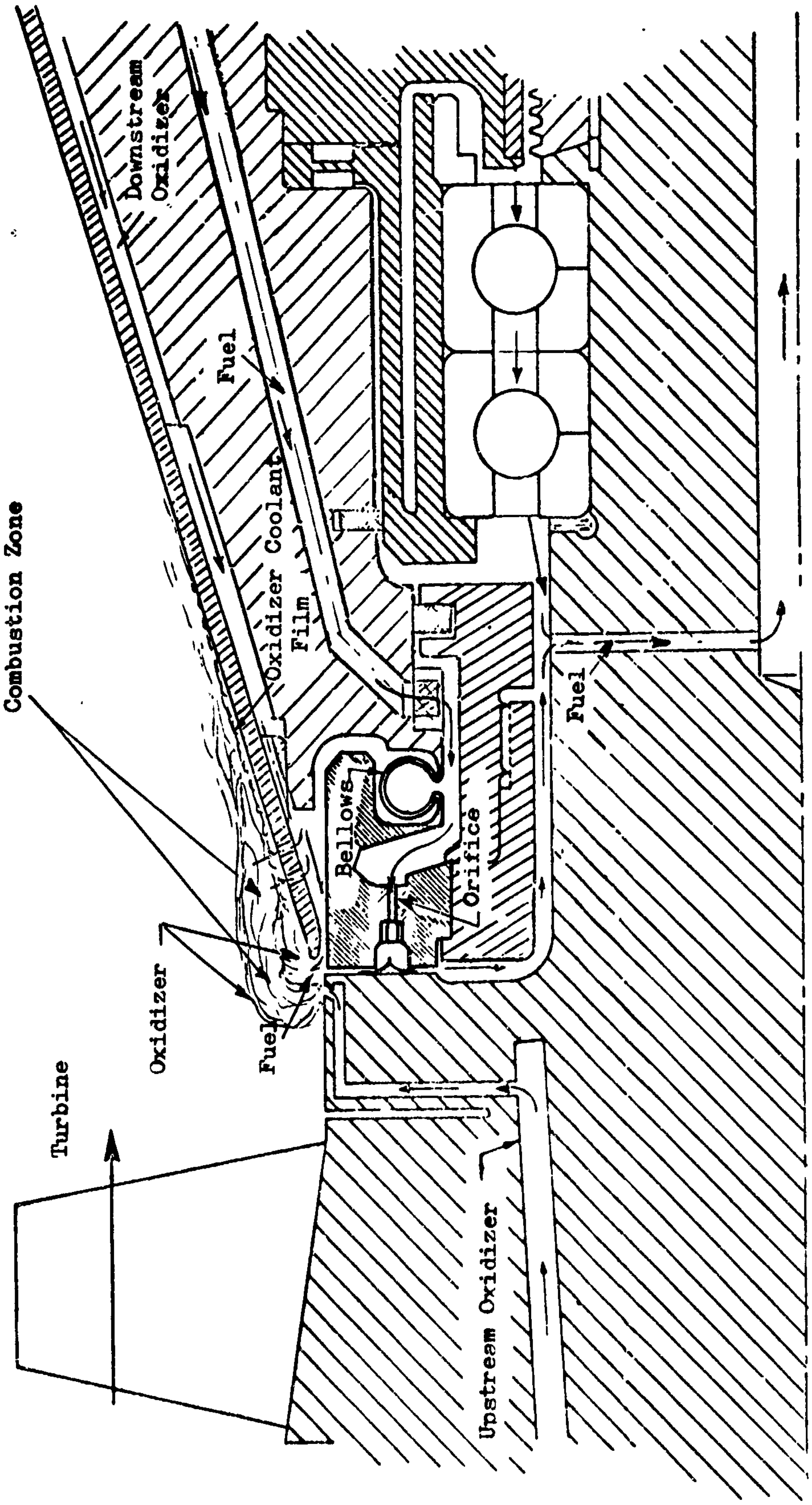
* Wt, lb
** I_p, in-lb sec^2



ARES Allowable Bearing Misalignment

22 December 1965

Figure I-3.7.2-2



Hydrostatic Combustion Seal (U)

4.0 BOOST PUMP ASSEMBLIES

4.1 OXIDIZER BOOST PUMP ASSEMBLY

4.1.1 Description

The oxidizer boost pump assembly is shown in Figure I-4.1.1-1.

4.1.2 Specification

The hydraulic turbine specification for design is shown in Table I-4.1.2-1; the boost pump specification for design is shown in Table I-4.1.2-2.

4.1.3 Performance

The predicted boost-pump performance is shown in Figure I-4.1.3-1; the predicted hydraulic turbine performance is shown in Figure I-4.1.3-2. The predicted hydraulic turbine performance is shown in Figure I-4.1.3-3.

4.2 FUEL BOOST PUMP ASSEMBLY

4.2.1 Description

The fuel boost pump assembly is shown in Figure I-4.2.1-1.

4.2.2 Specification

The hydraulic turbine specification for design is shown in Table I-4.1.2-1 and the boost pump specification for design is shown in Table I-4.1.2-2.

4.2.3 Performance

The predicted boost pump performance is shown in Figure I-4.1.3-1; the predicted head loss due to cavitation is shown in Figure I-4.1.3-2. The predicted hydraulic turbine performance is shown in Figure I-4.2.3-1.

Table I-4.1.2-1

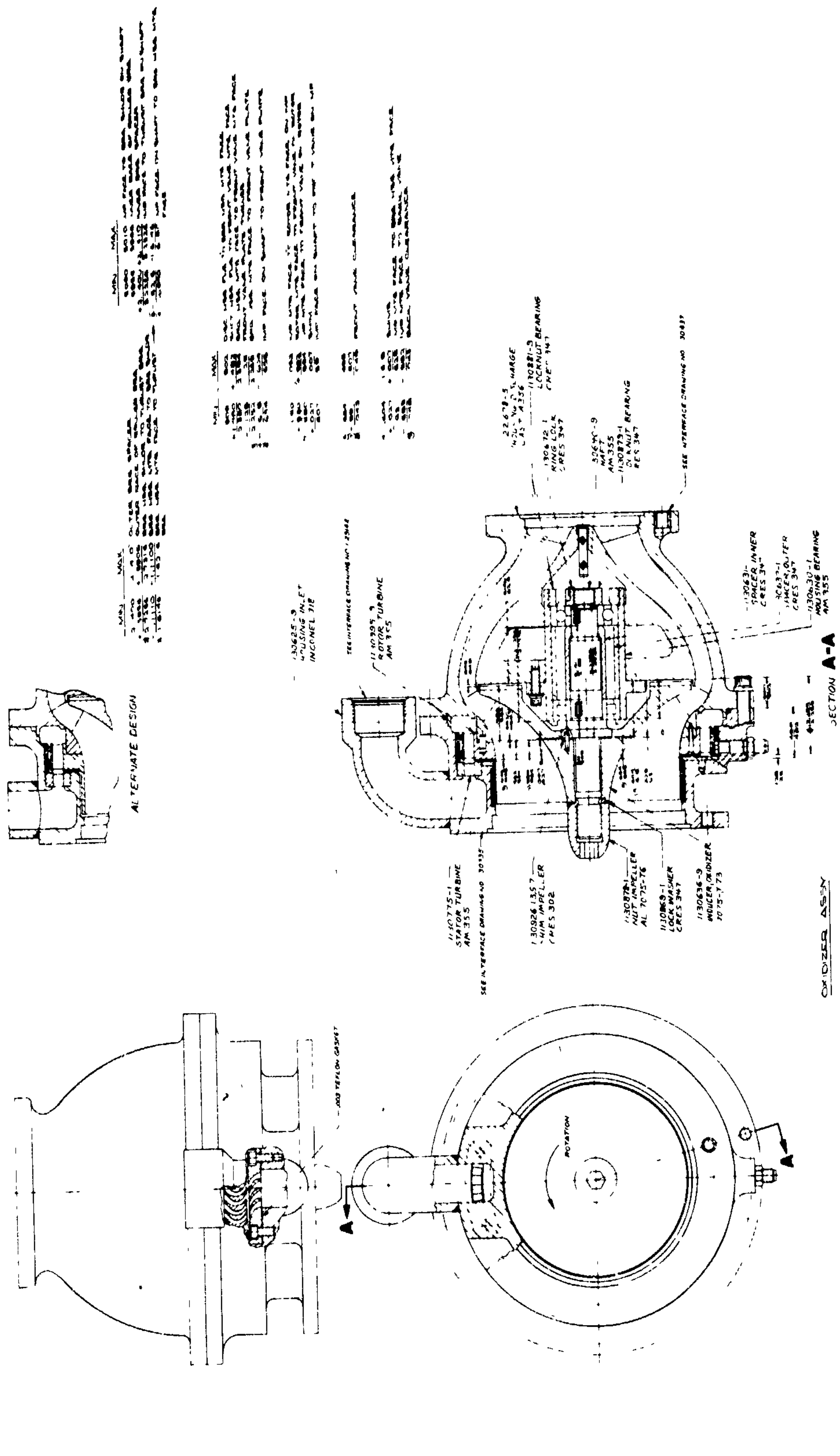
ARES HYDRAULIC TURBINE DESIGN SPECIFICATION (U)

	HYDRAULIC DESIGN PT	MAXIMUM STRESS CONDITION
Temperature - °F		
T_{TITOBP}	94	94
T_{TITFBP}	89	89
Density - lb/ft^3		
ρ_{OTBP}	89.5	89.5
ρ_{FTBP}	56.1	56.1
Vapor Pressure - PSIA		
P_{OVTBP}	27	
P_{FVTBP}	3.6	
Shaft Power - HP		
SHP_{OTBP}	306	407
SHP_{FTBP}	118	157
Shaft Speed - RPM		
N_{OTBP}	8,000	8,800
N_{FTBP}	8,000	8,800
Inlet Port Total Pressure - PSIA		
P_{TITOBP}	5,600	7,000
P_{TITFBP}	3,440	4,300
Exit Total Pressure - PSIA		
P_{TETOBP}	300	
P_{TITFBP}	170	
Exit Static Pressure - PSIA		
P_{TESOBP}	260	
P_{TESFBP}	140	
Flow Rate - lb/sec		
$\dot{W}_{OTBP}$	40	
$\dot{W}_{FTBP}$	18	
Efficiency - % (Minimum)		
η_{OTBP}	50	
η_{FTBP}	43	

Table I-4.1.2-2

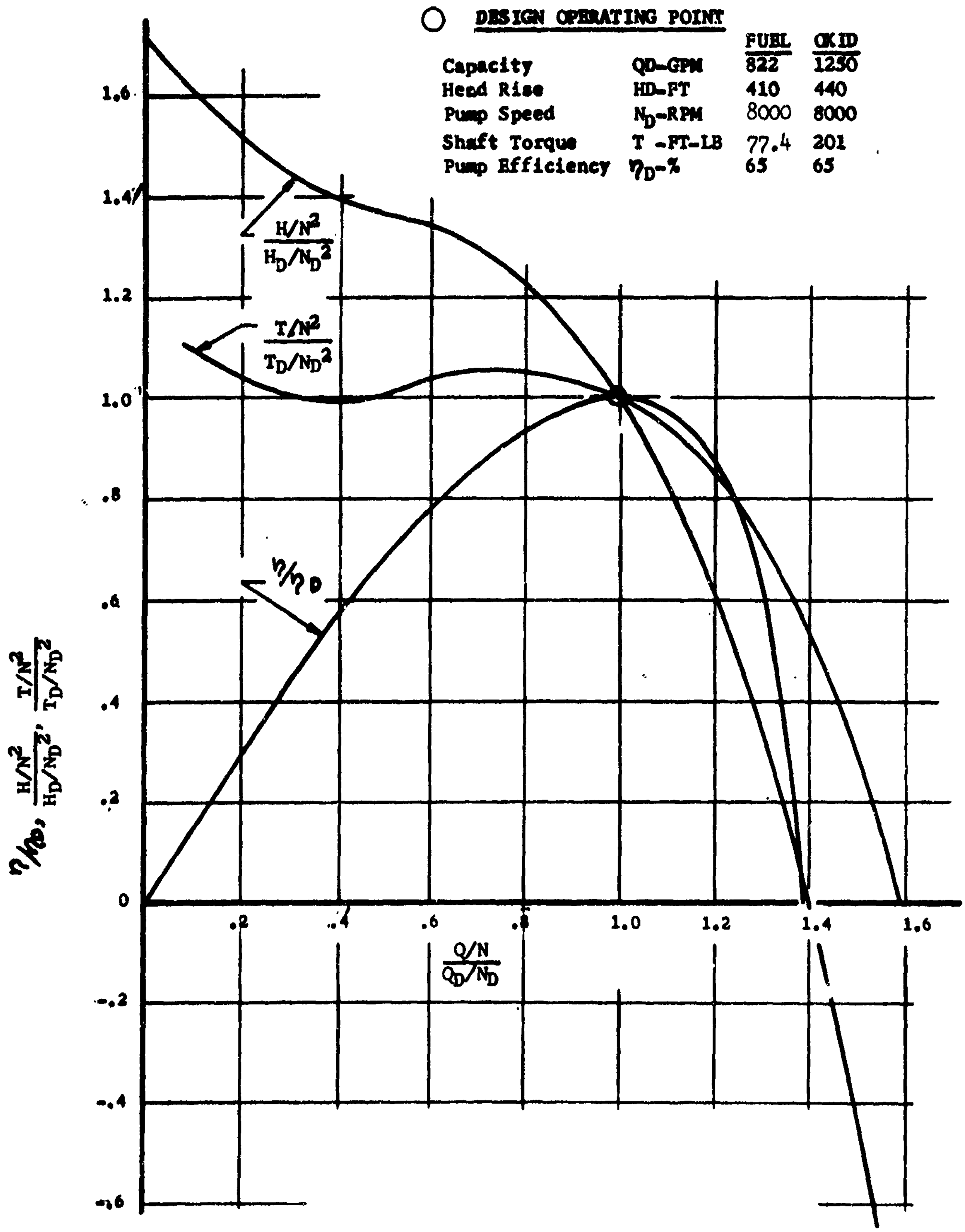
ARES BOOST PUMP
DESIGN SPECIFICATION (U)

	HYDRAULIC DESIGN PT.	MAXIMUM STRESS PT.
Temperature - °F	77	77
Density - lb/ft^3		
γ_{OSBP}	89.5	89.5
γ_{FSBP}	56.1	56.1
Vapor Pressure - lb/in^2		
P_{OVBP}	18	-
P_{FVBP}	2.8	-
Speed - RPM		
N_{OTBP}	8000	8800
N_{FTBP}	8000	8800
Head Rise - FT		
H_{ODBP}	440	540
H_{FDBP}	410	500
Flow Rate - GPM		
Q_{OSBP}	1250	1375
Q_{FSBP}	322	905
Efficiency - % (Minimum)		
η_{OBP}	65	-
η_{FBP}	65	-
Net Positive Suction Head - FT		
$NPSH_{OSBP}$	11.6	-
$NPSH_{FSBP}$	7.8	-
Shaft Power - HP		
SHP_{OBP}	-	407
SHP_{FBP}	-	157
Pump Discharge Pressure - PSIA		
P_{ODBP}	-	410
P_{FDBP}	-	375



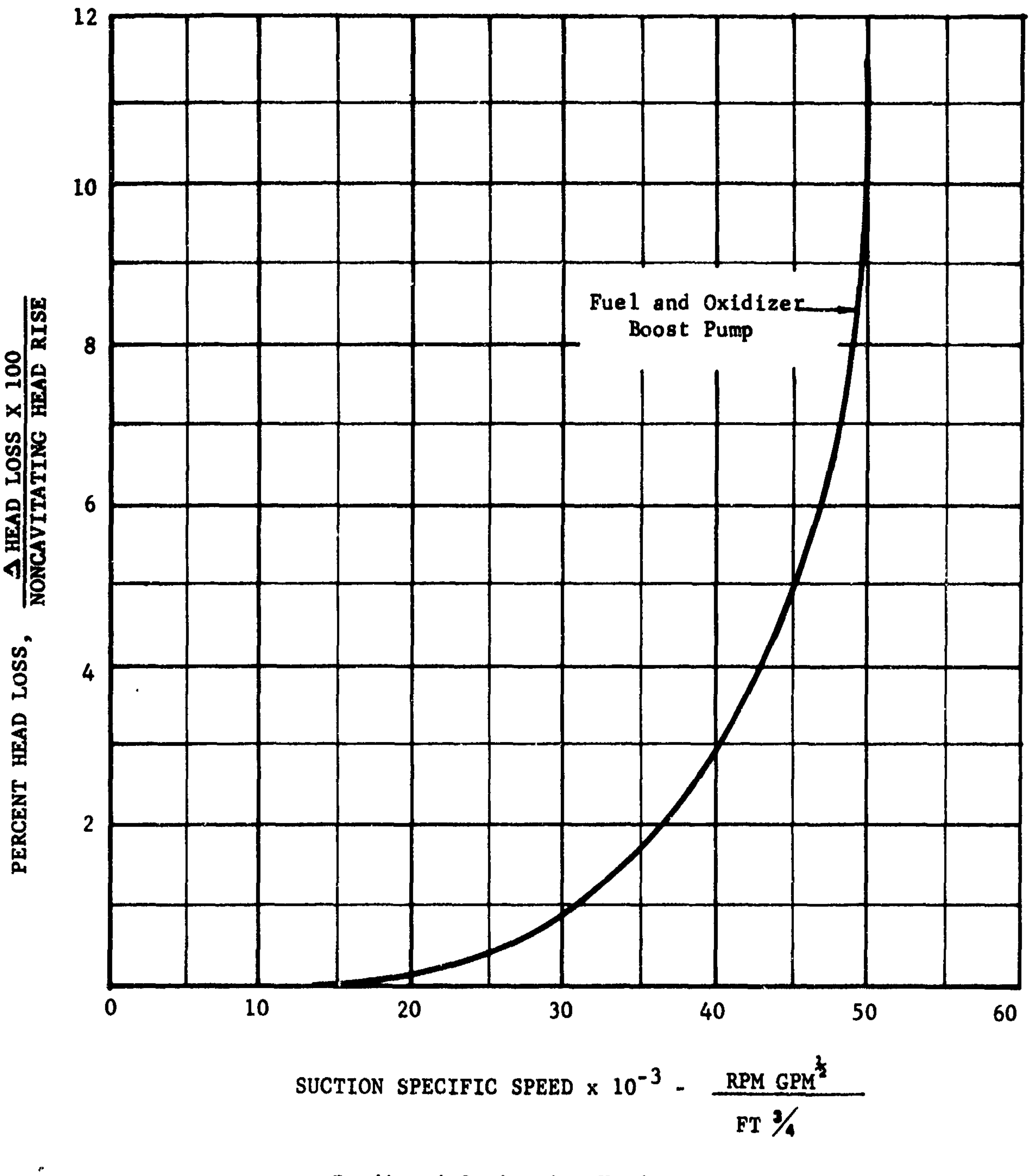
Oxidizer Boost Turbopump

Figure I-4.1.1-1

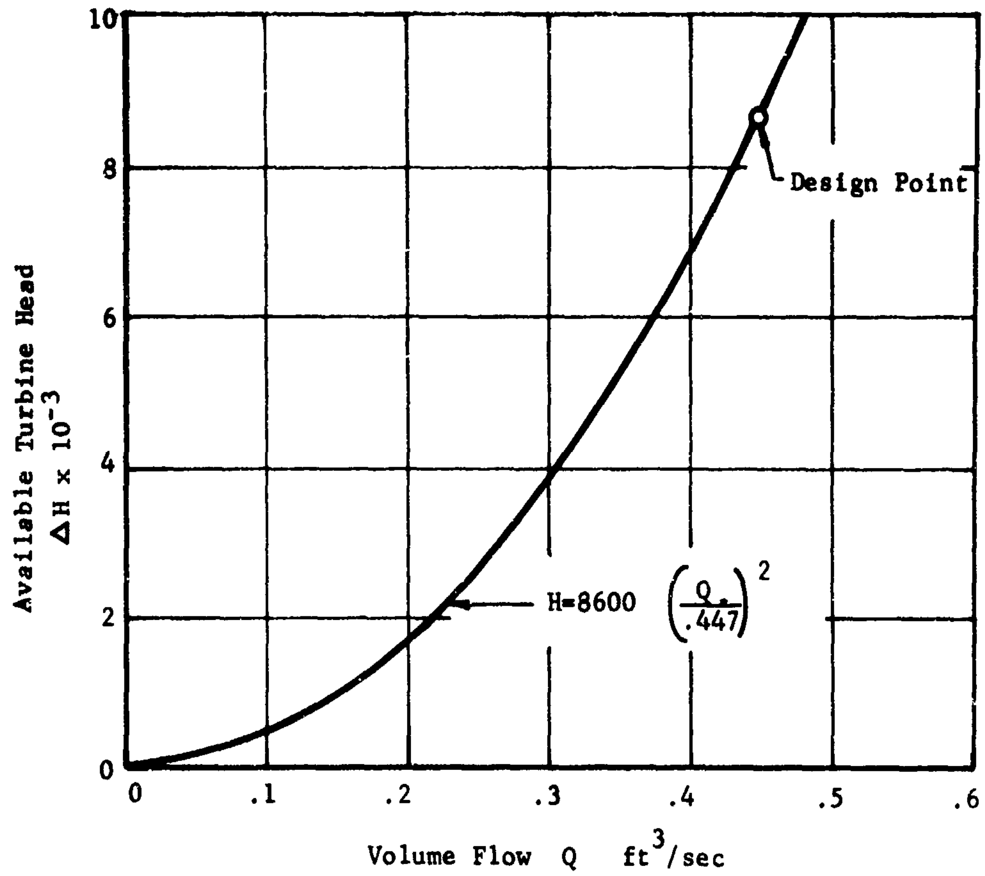


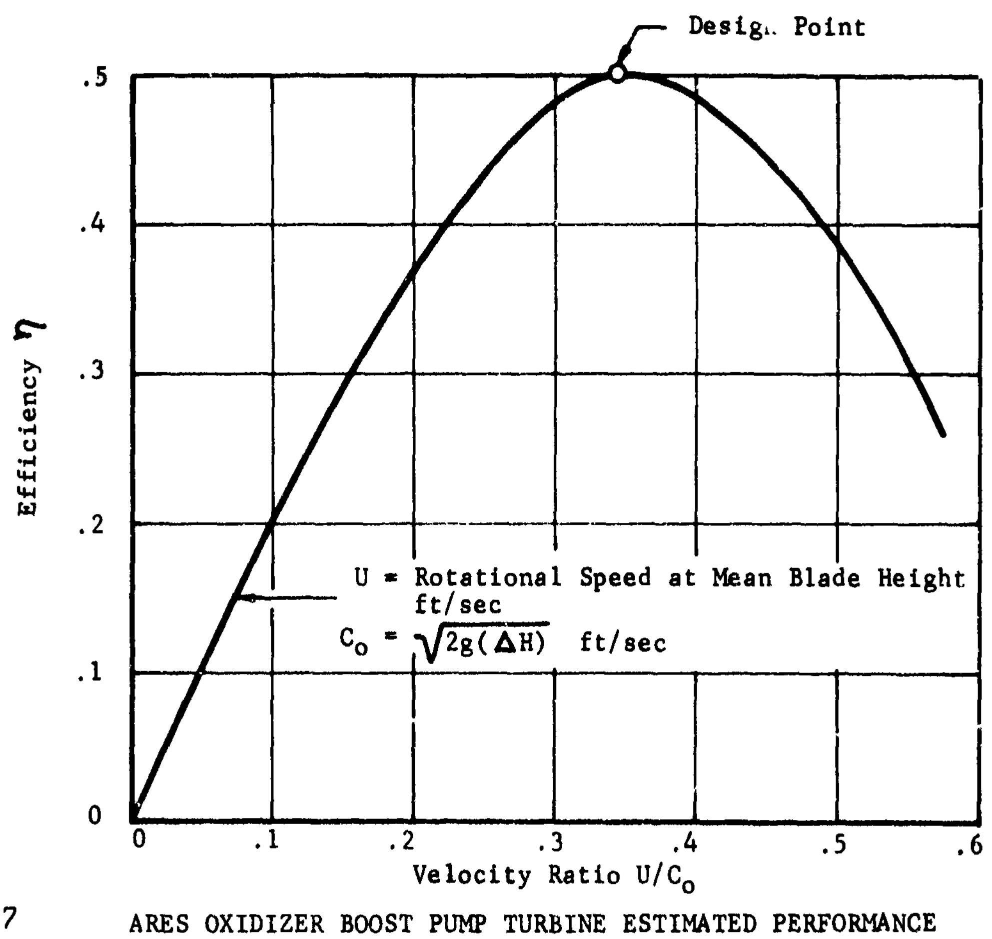
Predicted Oxidizer and Fuel Boost Pump Performance (u)

Figure I-4.1.3-1



Predicted Cavitating Head Loss, Boost Pumps

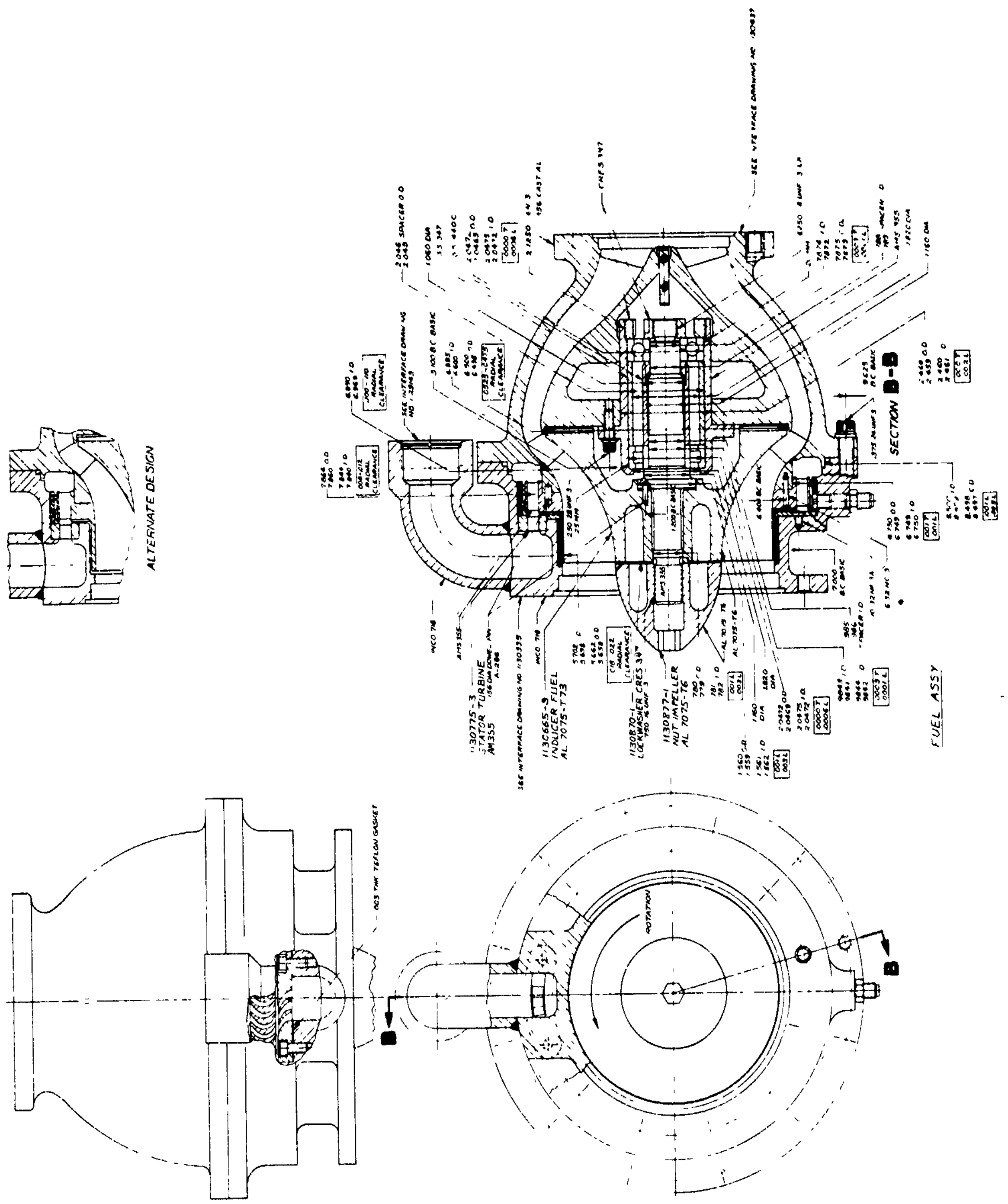




10 March 1967

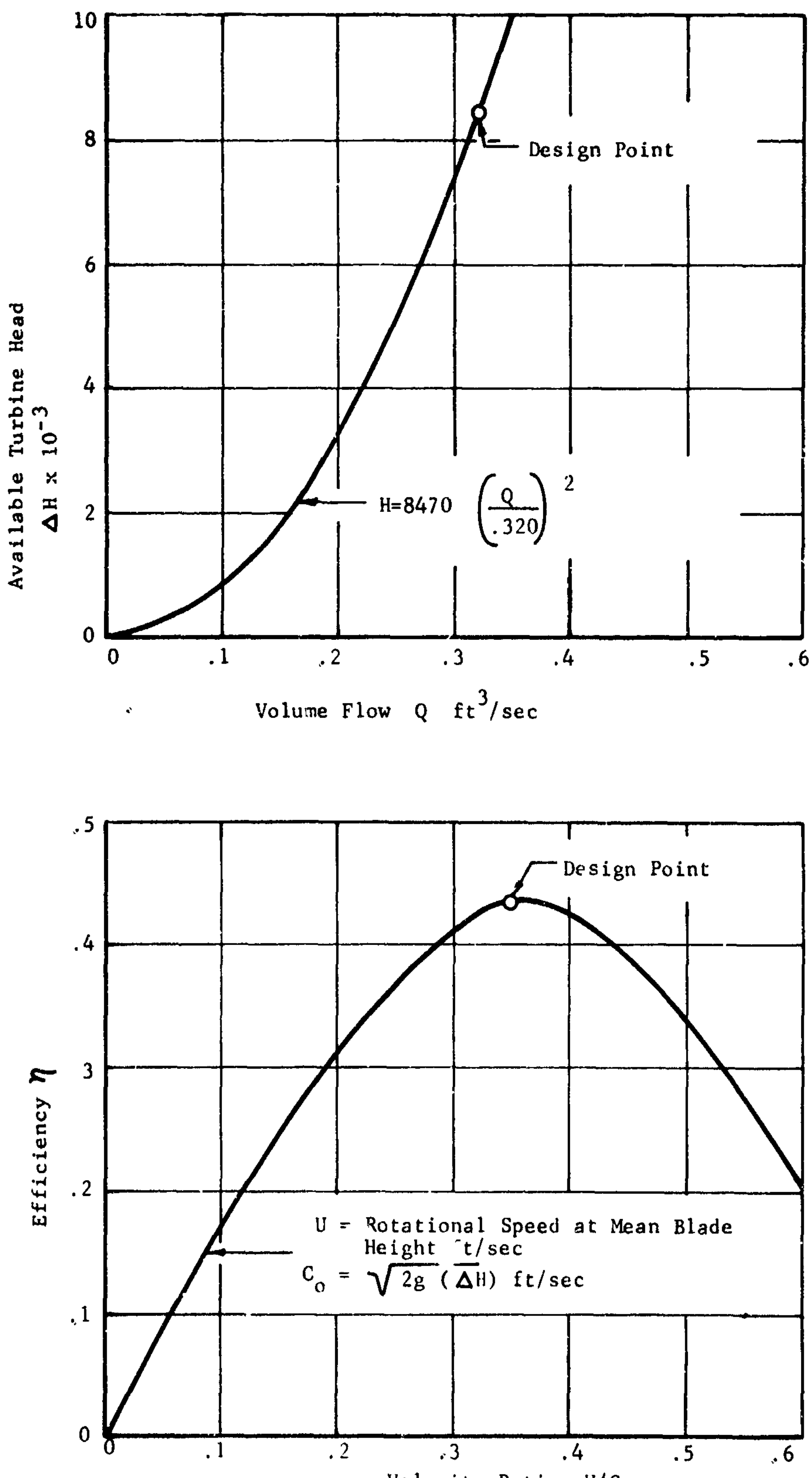
ARES OXIDIZER BOOST PUMP TURBINE ESTIMATED PERFORMANCE

Figure I-4.1.3-3



Fuel Boost Turbopump

Figure I-4.2.1-1



10 March 1967 ARES FUEL BOOST PUMP TURBINE ESTIMATED PERFORMANCE

Figure I-4.2.3-1

5.0 PRIMARY COMBUSTOR

5.1 DESCRIPTION

The primary combustor concept is shown in Figure I-2.1-2. An injector concept is shown in Figure I-5.1-1.

5.2 SPECIFICATION

The primary combustor nominal operating point flow and pressure schedule are shown in Figure I-2.6-1 and Tables I-2.6-1 and I-2.6-2.

5.3 PERFORMANCE

The primary combustor predicted nominal operating point performance, in conjunction with module operating performance is shown in Table I-2.7-1.

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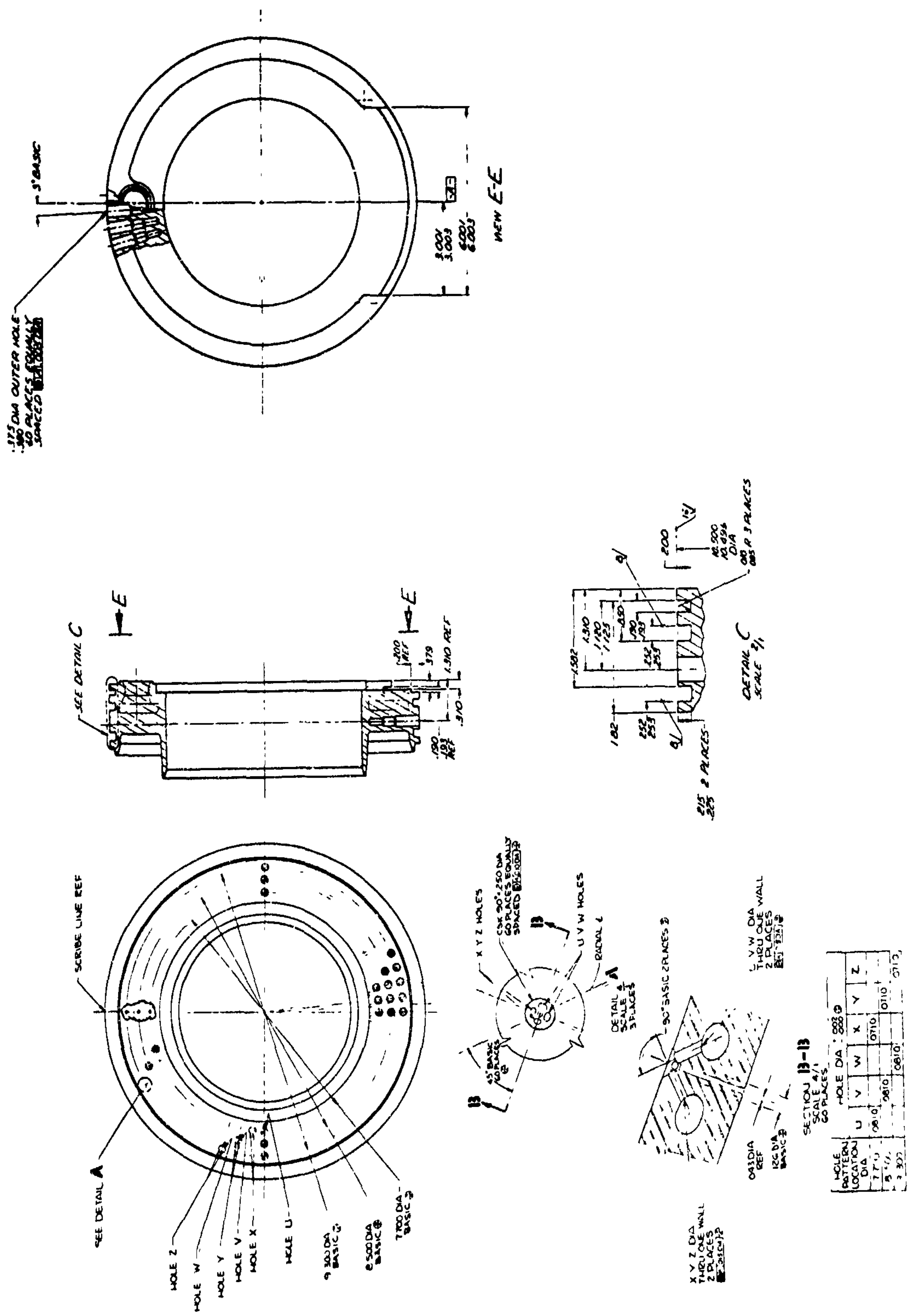

Primary Injector, Pentad

Figure I-5.1-1

UNCLASSIFIED

6.0 SECONDARY COMBUSTOR

6.1 DESCRIPTION

The secondary combustor regeneratively cooled concept with film cooling at two points is shown in Figure I-6.1-2. The chamber internal contour is shown in Figure I-6.1-1. An injector concept is shown in Figure I-6.1-3.

6.2 SPECIFICATION

The secondary combustor nominal operating point flow and pressure schedule are shown in Figure I-2.6-1 and Tables I-2.6-1, and I-2.6-2.

6.3 PERFORMANCE

The secondary combustor predicted nominal operating point performance in conjunction with module operating performance is shown in Table I-2.7-1. The predicted secondary combustor performance vs oxidizer film cooling flow rate is shown in Figure I-6.3-1. The effects of oxidizer film cooling and characteristic length on injector performance are shown in Figures I-6.3-2 and I-6.3-3, respectively. A summary of predicted performance data based on preliminary testing of the regeneratively cooled secondary combustor is shown in Table I-6.3-1.

Theoretical performance at various mixture ratios and expansion ratios, with 100% efficiencies and no film cooling, is shown in Table I-6.3-2.

Table I-6.3-1

PREDICTED ARES THRUST CHAMBER PERFORMANCE (U)

1. CONDITION

Secondary Injector:	Mark 125 with even M.R. distribution
Nozzle Extension:	80% Bell Contour
Chamber Cooling System:	Oxidizer regenerative plus film cooling
A_e/A_t = 20:1;	L* = 39.0 in.
P_c = 2800 psia:	MR_J = 2.20
$\hat{W}_e$ = 350.9 lbm/sec;	$\hat{W}_{ox.FC}$ = 18.0 lbm/sec (5.1%)

2. THEORETICAL PERFORMANCE:

I_s, vac (shifting equilibrium) = 329.5 sec.

$I_{s,\ sl}$ = 310.9 sec

3. PERFORMANCE LOSSES:

Type	I_s(sec)	$\%\Delta I_{sv}$	$\%\Delta I_{s,chamber}$	$\%\Delta I_{s,\ nozzle\ v}$
Mixture Ratio Distribution	0.0	0.0	0.0	0.0
Combustion	11.2	3.4	1.82	1.58
Nozzle Friction	3.1	1.0	0.0	1.0
Nozzle Geometry	2.9	0.9	0.0	0.9
Oxid. Film Cooling	8.7	2.6	1.7	0.9
TOTAL LOSSES	25.9	7.9	3.52	4.38

4. PREDICTED DELIVERED PERFORMANCE:

	Sea Level		Vacuum	
	Value	Percent	Value	Percent
Specific Impulse, I_s	285.0 sec	91.66	303.6 sec	92.14
Characteristic Exhaust Velocity, c*	5485 ft/sec	96.48	5485 ft/sec	96.48
Thrust Coefficient, C_f	1.672	95.10	1.780	95.50
Film Coolant Flow, W_oFC	18.0 lb/sec	5.1	18.0 lb/sec	5.1
Thrust	100,000 lb	---	106,533 lb	---

Table I-6.3-1

Table I-6.3-2

THEORETICAL PERFORMANCE PARAMETERS AT VARIOUS MIXTURE & EXPANSION RATIOS

Propellants: N_2O_4/A-50
Combustion & nozzle efficiencies: 100%
Film cooling flow rate: None
Chamber pressure, P_c: 2800 psia

A_E/A_T Nozzle area ratio
C* Characteristic velocity, ft/sec
C_FVAC Thrust coefficient in vacuum
C_FSL Thrust coefficient at sea level
I_sVAC Specific impulse, sec, in vacuum
I_sSL Specific impulse, sec, at sea level
MR Mixture ratio, oxidizer/fuel
T_{CT} Total temperature in chamber, °R
T_{ES} Static temperature at exit plane, °R

MR	C*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
A_E/A_T = 1.00							
1.40	5737	1.243	1.238	221.7	220.7	5557	5043
1.60	5793	1.240	1.234	223.2	222.3	5905	5429
1.80	5805	1.237	1.231	223.1	222.2	6126	5707
2.00	5768	1.235	1.229	221.4	220.4	6221	5845
2.10	5735	1.234	1.229	220.0	219.1	6230	5865
2.20	5694	1.234	1.229	218.4	217.5	6222	5866
2.40	5605	1.234	1.229	215.0	214.1	6170	5814
2.60	5512	1.234	1.229	211.4	210.5	6089	5725
2.80	5417	1.235	1.229	207.9	207.0	5992	5622
3.00	5328	1.235	1.230	204.6	203.7	5890	5514
A_E/A_T = 2.00							
1.40	5737	1.459	1.448	260.1	258.3	5557	3761
1.60	5793	1.460	1.449	262.9	261.0	5905	4168
1.80	5805	1.463	1.452	263.9	262.1	6126	4549
2.00	5768	1.467	1.456	263.0	261.1	6221	4861
2.10	5735	1.468	1.457	261.6	259.8	6230	4950
2.20	5694	1.468	1.457	259.8	258.0	6222	4980
2.40	5605	1.468	1.457	255.7	253.9	6170	4922
2.60	5512	1.467	1.456	251.3	249.5	6089	4803
2.80	5417	1.466	1.456	246.9	245.1	5992	4665
3.00	5328	1.465	1.455	242.7	241.0	5890	4526
A_E/A_T = 4.00							
1.40	5737	1.595	1.574	284.5	280.8	5557	3050
1.60	5793	1.599	1.578	287.9	284.1	5905	3421
1.80	5805	1.606	1.585	289.9	286.1	6126	3791
2.00	5768	1.617	1.596	289.9	286.1	6221	4164
2.10	5735	1.621	1.600	289.0	285.2	6230	4331
2.20	5694	1.623	1.602	287.4	283.6	6222	4422
2.40	5605	1.623	1.602	282.7	279.0	6170	4349
2.60	5512	1.619	1.598	277.5	273.9	6089	4190
2.80	5417	1.617	1.596	272.3	268.7	5992	4027
3.00	5328	1.614	1.593	267.4	263.9	5890	3870

23 November 1966

Table I-6.3-2 (cont.)

MR	C*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
A_E/A_T = 6.00							
1.40	5737	1.654	1.623	295.0	289.4	5557	2710
1.60	5793	1.662	1.630	299.2	293.6	5905	3060
1.80	5805	1.672	1.641	301.8	296.1	6126	3411
2.00	5768	1.687	1.655	302.4	296.8	6221	3776
2.10	5735	1.693	1.662	301.9	296.2	6230	3963
2.20	5694	1.695	1.664	300.1	294.5	6222	4108
2.40	5605	1.694	1.662	295.1	289.6	6170	4023
2.60	5512	1.692	1.660	289.9	284.5	6089	3845
2.80	5417	1.688	1.656	284.2	278.9	5992	3674
3.00	5328	1.684	1.652	278.9	273.7	5890	3517
A_E/A_T = 8.00							
1.40	5737	1.692	1.650	301.7	294.2	5557	2495
1.60	5793	1.701	1.659	306.2	298.7	5905	2828
1.80	5805	1.713	1.671	309.1	301.5	6126	3164
2.00	5768	1.726	1.684	309.5	302.0	6221	3516
2.10	5735	1.734	1.692	309.2	301.7	6230	3706
2.20	5694	1.741	1.699	308.1	300.7	6222	3883
2.40	5605	1.738	1.696	302.9	295.6	6170	3793
2.60	5512	1.733	1.691	296.9	289.7	6089	3606
2.80	5417	1.728	1.686	291.0	283.9	5992	3433
3.00	5328	1.723	1.681	285.4	278.5	5890	3278
A_E/A_T = 10.00							
1.40	5737	1.715	1.662	305.6	296.4	5557	2338
1.60	5793	1.725	1.672	310.6	301.2	5905	2658
1.80	5805	1.739	1.686	313.8	304.3	6126	2983
2.00	5768	1.758	1.705	315.2	305.8	6221	3327
2.10	5735	1.767	1.715	315.1	305.7	6230	3513
2.20	5694	1.775	1.722	314.2	304.9	6222	3704
2.40	5605	1.773	1.720	308.8	299.7	6170	3616
2.60	5512	1.766	1.713	302.6	293.6	6089	3426
2.80	5417	1.760	1.708	296.4	287.6	5992	3254
3.00	5328	1.755	1.702	290.7	282.0	5890	3102
A_E/A_T = 15.00							
1.40	5737	1.756	1.678	313.2	299.2	5557	2084
1.60	5793	1.768	1.690	318.4	304.2	5905	2379
1.80	5805	1.784	1.706	322.0	307.8	6126	2682
2.00	5768	1.806	1.727	323.9	309.7	6221	3005
2.10	5735	1.818	1.739	324.0	310.0	6230	3182
2.20	5694	1.828	1.749	323.5	309.6	6222	3378
2.40	5605	1.825	1.746	317.9	304.2	6170	3299
2.60	5512	1.816	1.738	311.3	297.8	6089	3111
2.80	5417	1.810	1.731	304.7	291.5	5992	2945
3.00	5328	1.803	1.724	298.7	285.6	5890	2799

Table I-6.3-2 (cont.)

A_E/A_T = 20.00

MR	C*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
1.40	5737	1.783	1.678	317.9	299.2	5557	1921
1.60	5793	1.796	1.691	323.4	304.5	5905	2199
1.80	5805	1.814	1.709	327.3	308.3	6126	2487
2.00	5768	1.837	1.732	329.5	310.7	6221	2796
2.10	5735	1.850	1.745	329.9	311.1	6230	2965
2.20	5694	1.862	1.757	329.5	310.9	6222	3155
2.40	5605	1.859	1.754	323.8	305.5	6170	3084
2.60	5512	1.849	1.744	316.9	298.9	6089	2900
2.80	5417	1.842	1.737	310.1	292.4	5992	2740
3.00	5328	1.834	1.729	303.8	286.4	5890	2599

A_E/A_T = 25.00

MR	C*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
1.40	5737	1.803	1.672	321.6	298.2	5557	1808
1.60	5793	1.817	1.686	327.2	303.6	5905	2073
1.80	5805	1.836	1.704	331.2	307.6	6126	2348
2.00	5768	1.857	1.726	333.0	309.4	6221	2639
2.10	5735	1.871	1.739	333.5	310.1	6230	2802
2.20	5694	1.883	1.752	333.3	310.1	6222	2986
2.40	5605	1.880	1.749	327.5	304.7	6170	2920
2.60	5512	1.870	1.738	320.4	297.9	6089	2741
2.80	5417	1.861	1.730	313.5	291.4	5992	2585
3.00	5328	1.854	1.722	307.0	285.3	5890	2449

A_E/A_T = 30.00

MR	C*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
1.40	5737	1.815	1.658	323.7	295.6	5557	1717
1.60	5793	1.830	1.673	329.5	301.2	5905	1970
1.80	5805	1.850	1.692	333.8	305.4	6126	2235
2.00	5768	1.876	1.719	336.4	308.2	6221	2522
2.10	5735	1.891	1.733	337.1	309.0	6230	2680
2.20	5694	1.904	1.747	337.1	309.2	6222	2859
2.40	5605	1.901	1.743	331.2	303.7	6170	2796
2.60	5512	1.890	1.732	323.8	296.9	6089	2620
2.80	5417	1.881	1.724	316.8	290.3	5992	2468
3.00	5328	1.873	1.715	310.2	284.1	5890	2335

A_E/A_T = 40.00

MR	C*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
1.40	5737	1.837	1.628	327.7	290.3	5557	1594
1.60	5793	1.854	1.644	333.8	296.0	5905	1823
1.80	5805	1.874	1.664	338.2	300.3	6126	2073
2.00	5768	1.902	1.692	341.0	303.4	6221	2344
2.10	5735	1.913	1.703	341.0	303.5	6230	2487
2.20	5694	1.927	1.717	341.2	304.0	6222	2657
2.40	5605	1.924	1.714	335.2	298.6	6170	2598
2.60	5512	1.912	1.702	327.6	291.6	6089	2430
2.80	5417	1.902	1.692	320.4	285.0	5992	2284
3.00	5328	1.898	1.688	314.4	279.6	5890	2163

Table I-6.3-2 (cont.)

A_E/A_T = 50.00

MR	θ*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
1.40	5737	1.850	1.587	329.9	283.1	5557	1505
1.60	5793	1.867	1.604	336.1	288.9	5905	1711
1.80	5805	1.888	1.626	340.7	293.4	6126	1950
2.00	5768	1.918	1.655	343.9	296.8	6221	2209
2.10	5735	1.934	1.672	344.8	298.0	6230	2353
2.20	5694	1.950	1.688	345.2	298.7	6222	2516
2.40	5605	1.946	1.684	339.1	293.4	6170	2459
2.60	5512	1.933	1.671	331.3	286.3	6089	2296
2.80	5417	1.923	1.661	323.9	279.7	5992	2155
3.00	5328	1.914	1.651	317.0	273.5	5890	2032

A_E/A_T = 60.00

MR	θ*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
1.40	5737	1.864	1.549	332.4	276.2	5557	1459
1.60	5793	1.881	1.566	338.7	282.0	5905	1632
1.80	5805	1.903	1.588	343.3	286.5	6126	1860
2.00	5768	1.929	1.614	345.9	289.4	6221	2103
2.10	5735	1.946	1.631	346.9	290.7	6230	2242
2.20	5694	1.962	1.647	347.4	291.6	6222	2399
2.40	5605	1.958	1.643	341.2	286.3	6170	2344
2.60	5512	1.945	1.630	333.3	279.3	6089	2185
2.80	5417	1.934	1.619	325.7	272.7	5992	2048
3.00	5328	1.925	1.610	318.8	266.6	5890	1929

A_E/A_T = 80.00

MR	θ*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
1.40	5737	1.878	1.458	335.0	260.1	5557	1365
1.60	5793	1.896	1.476	341.4	265.8	5905	1507
1.80	5805	1.919	1.499	346.3	270.5	6126	1718
2.00	5768	1.951	1.531	349.8	274.5	6221	1952
2.10	5735	1.969	1.549	350.9	276.1	6230	2083
2.20	5694	1.986	1.566	351.6	277.2	6222	2232
2.40	5605	1.982	1.562	345.3	272.2	6170	2178
2.60	5512	1.968	1.548	337.2	265.3	6089	2026
2.80	5417	1.956	1.537	329.5	258.8	5992	1895
3.00	5328	1.946	1.526	322.3	252.8	5890	1781

A_E/A_T = 100.00

MR	θ*	C_FVAC	C_FSL	I_SVAC	I_SSL	T_{CT}	T_{ES}
1.40	5737	1.892	1.367	337.4	243.8	5557	1319
1.60	5793	1.910	1.385	343.9	249.4	5905	1420
1.80	5805	1.933	1.409	348.9	254.2	6126	1616
2.00	5768	1.966	1.441	352.5	258.4	6221	1839
2.10	5735	1.984	1.459	353.7	260.1	6230	1964
2.20	5694	2.000	1.475	354.0	261.1	6222	2103
2.40	5605	1.995	1.471	347.7	256.2	6170	2050
2.60	5512	1.983	1.458	339.8	249.9	6089	1907
2.80	5417	1.971	1.447	332.0	243.6	5992	1780
3.00	5328	1.961	1.436	324.8	237.8	5890	1671

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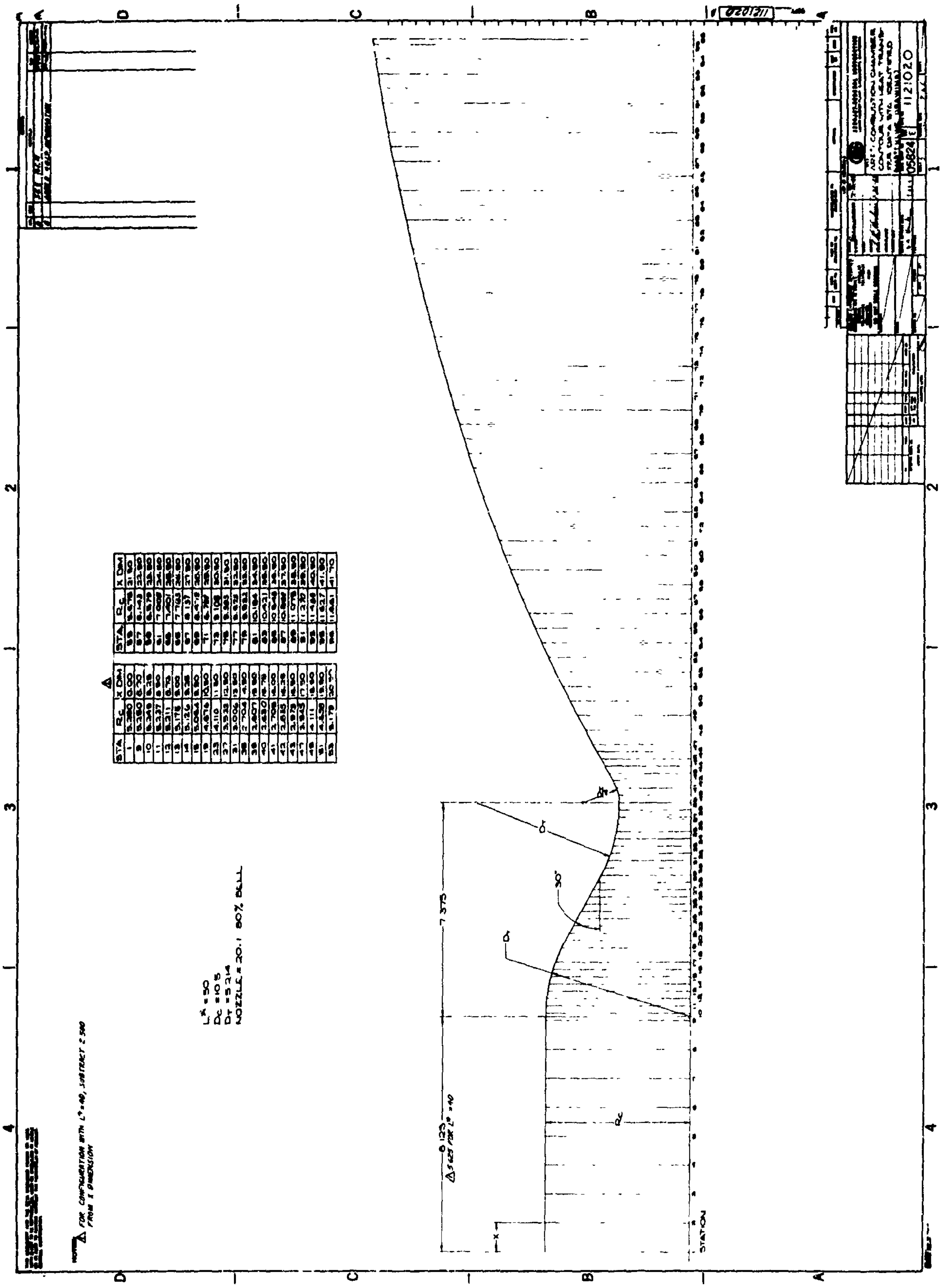

"ARES" Combustion Chamber Contour

Figure I-6.1-1

24 February 1966

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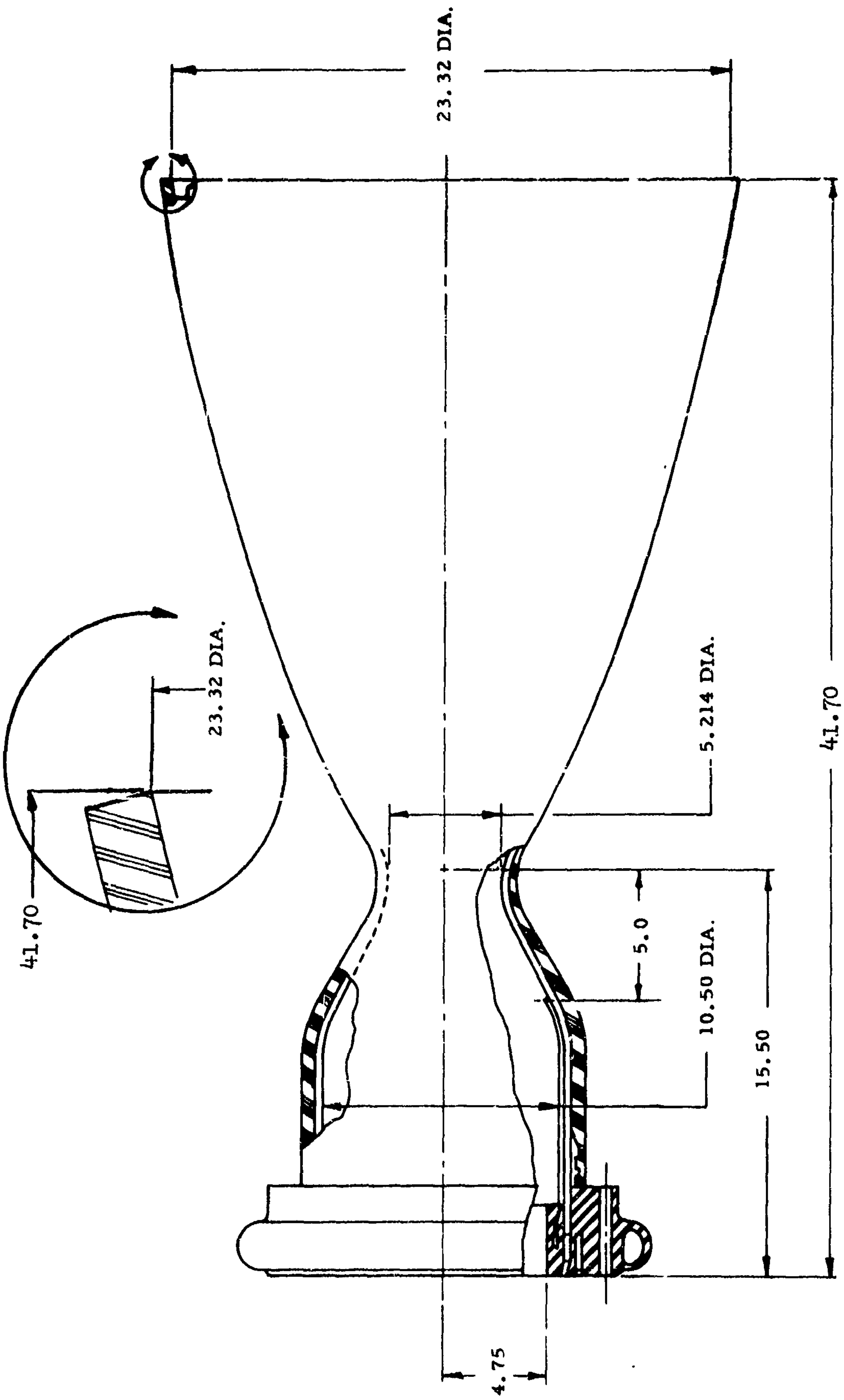


ARES REGENERATIVELY COOLED THRUST CHAMBER
L* = 40 IN.

CONFIDENTIAL

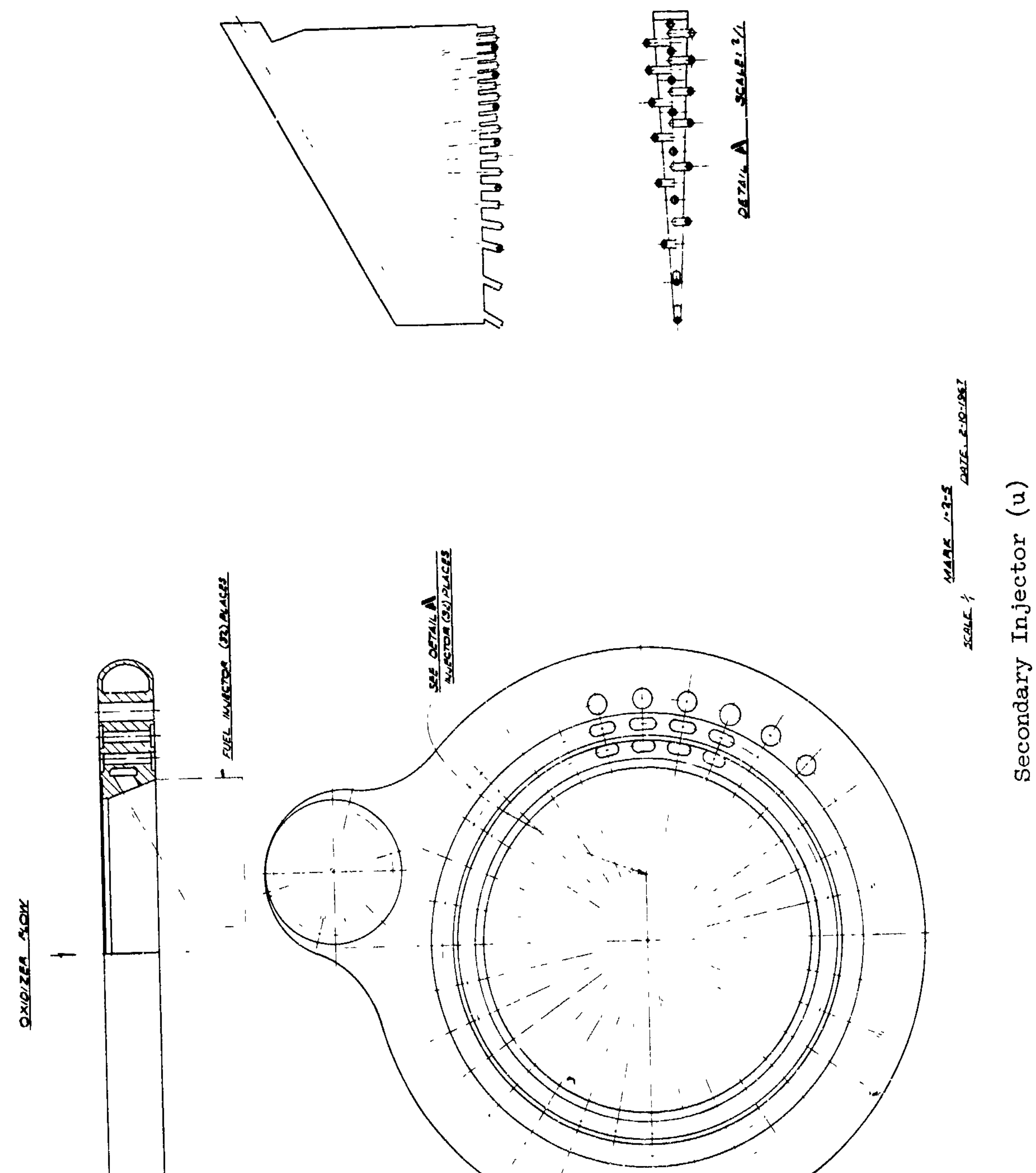
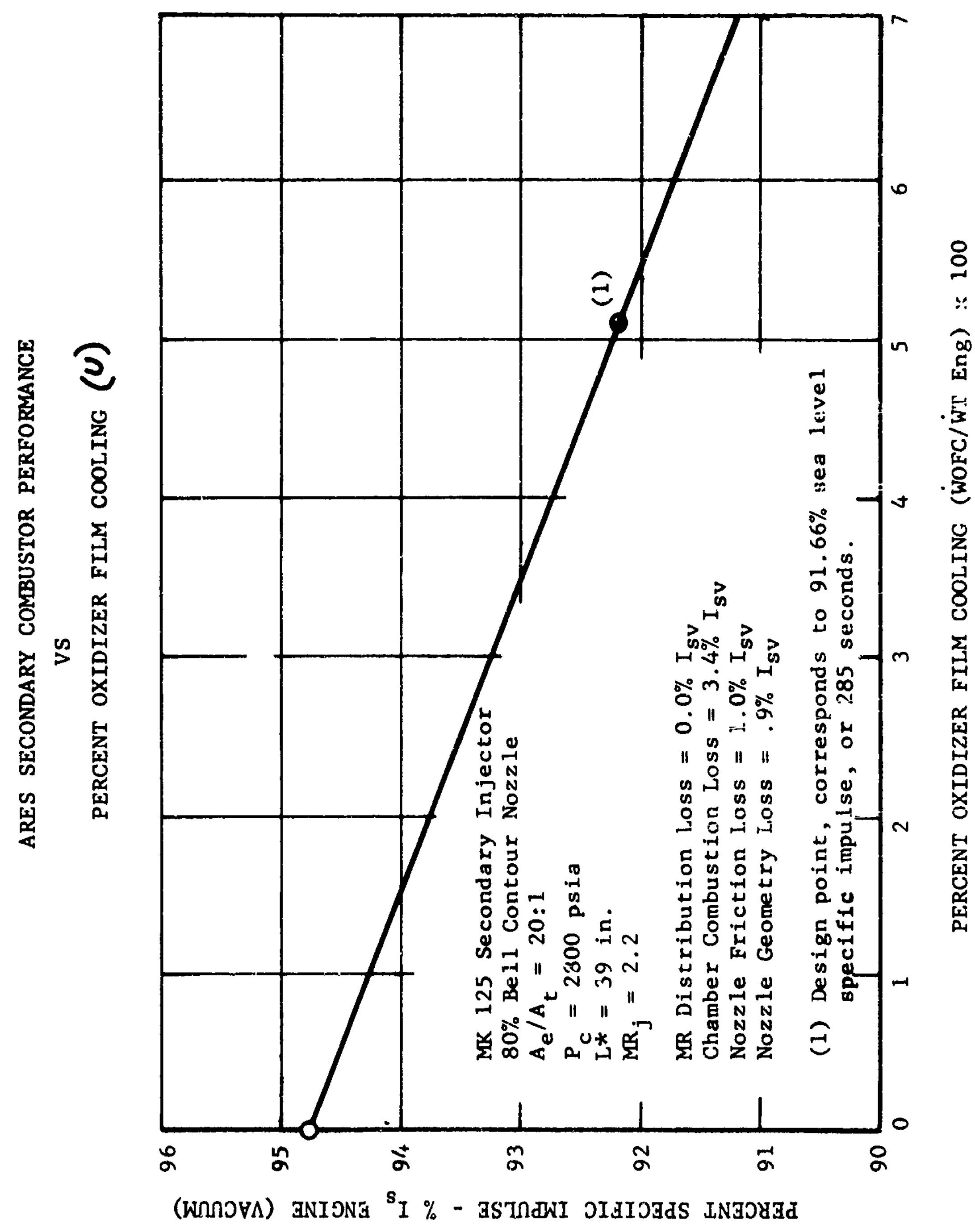


Figure I-6.1-3

CONFIDENTIAL



10 March 1967

Figure I-6.3-1

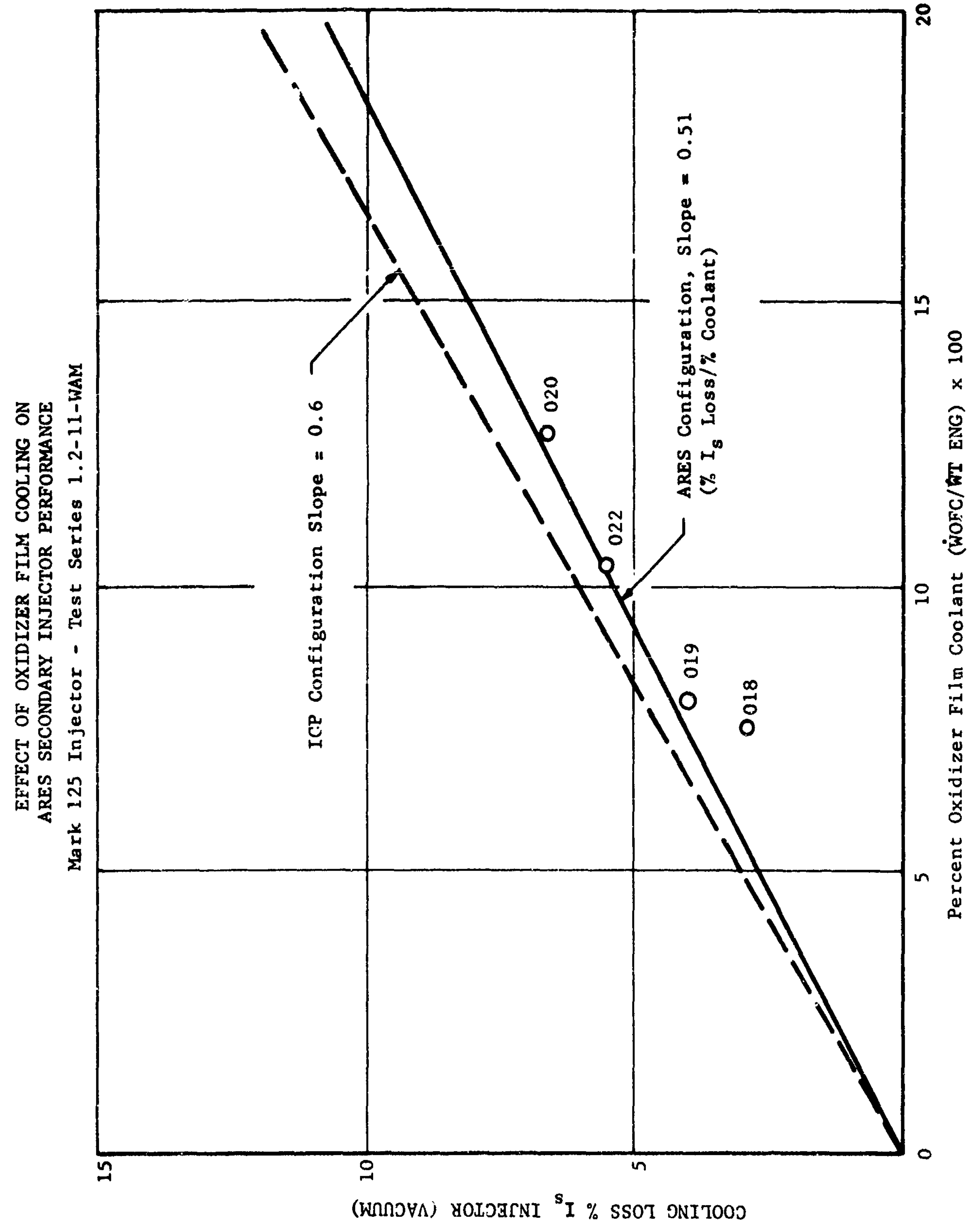
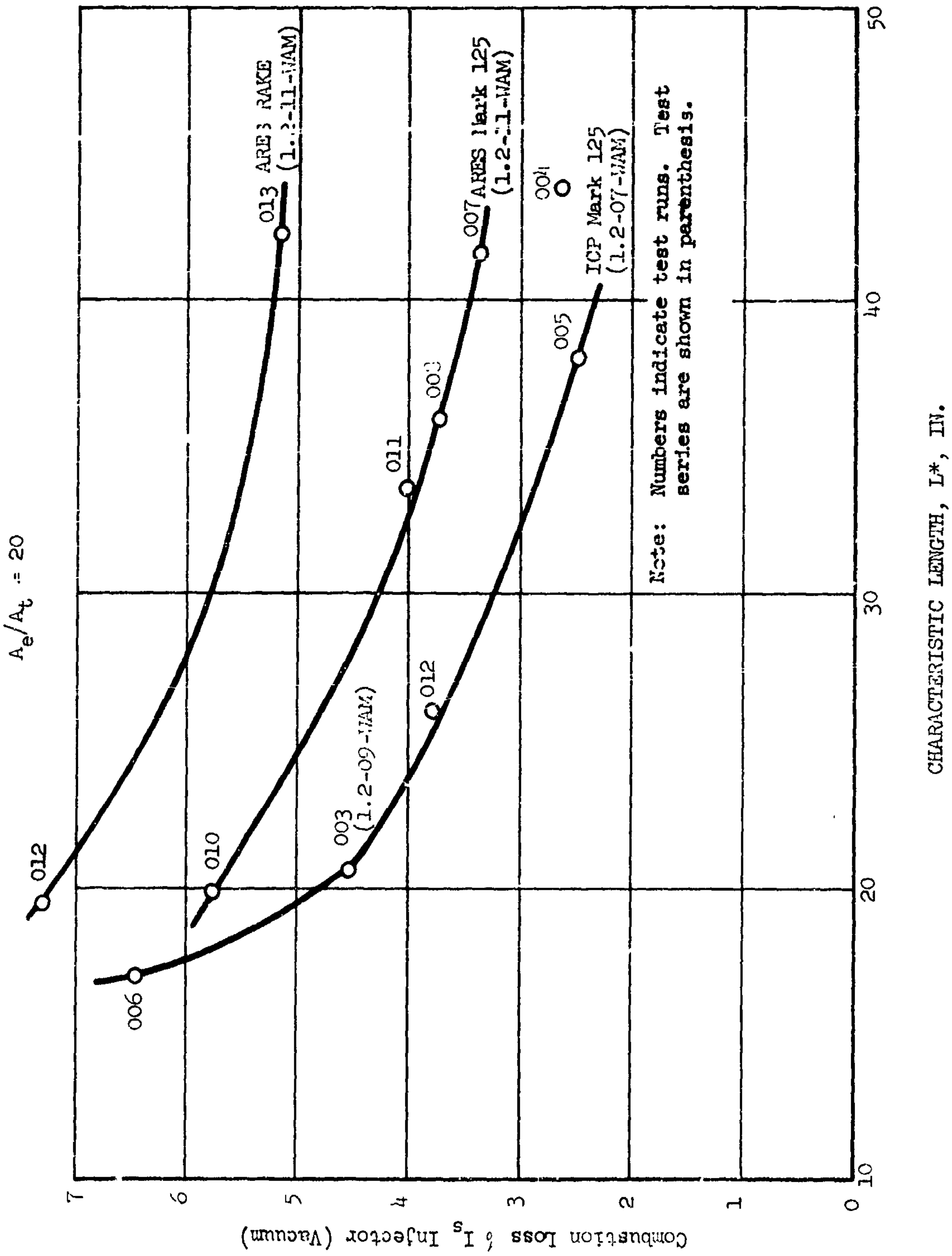

EFFECT OF OXIDIZER FILM COOLING ON
ARES SECONDARY INJECTOR PERFORMANCE
Mark 125 Injector - Test Series 1.2-11-WAM
ICP Configuration Slope = 0.6
ARES Configuration, Slope = 0.51
(% I_s Loss/% Coolant)
020
022
019
018
Percent Oxidizer Film Coolant ($\dot{W}$OFC/$\dot{W}$T ENG) x 100
0
5
10
15
20
COOLING LOSS % I_s INJECTOR (VACUUM)
0
5
10
15

Figure I-6.3-2



Effect of Characteristic Length on ARES Secondary Injector Performance

Figure I-6.3-3

7.0 CONTROLS

7.1 DESCRIPTION

7.1.1 Primary Combustor Fuel Control Valve (PCFCV)

The primary combustor fuel control valve concept is shown in Figure I-7.1.1-1.

7.1.2 Secondary Combustor Fuel Control Valve (SCFCV)

The secondary combustor fuel control valve concept is shown in Figure I-7.1.2-1.

7.2 SPECIFICATIONS

7.2.1 Primary Combustor Fuel Control Valve

The primary fuel control valve shall be designed to meet the engine flow and response requirements in Table I-7.2-1. Predicted performance of the valve as designed is included in the table.

7.2.2 Secondary Combustor Fuel Control Valve (SCFCV)

The secondary combustor fuel control valve shall be designed to meet the engine flow and response requirements in Table I-7.2-1. Predicted performance of the valve as designed is included in the table.

7.3 PERFORMANCE

7.3.1 Primary Combustor Fuel Control Valve (PCFCV)

The primary combustor fuel control valve hydraulic flow characteristics, K_W versus position, are shown in Figure I-7.3.1-1.

7.3.2 Secondary Combustor Fuel Control Valve (SCFCV)

The secondary combustor fuel control valve hydraulic flow characteristics, K_W versus position, are shown in Figure I-7.3.2-1.

	Primary Combustor Fuel Control Valve		Secondary Combustor Fuel Control Valve	
Minimum Flow Factor, $K_W = \dfrac{\dot{W}}{\Delta P \times S.G.}$	Required	Predicted	Required	Predicted
Full Open Position	1.40	1.85	7.00	7.50
Full Closed Position	0.02	0.015	0.10	0.06
Required Response Time, sec.				
Opening Time				
Minimum	0.025	0.010	0.025	0.015
Maximum	0.750	**	0.750	**
Closing Time				
Minimum	0.025	0.010	0.025	0.015
Maximum	0.750	**	0.750	**

** Limited only by command signal and position feedback control.

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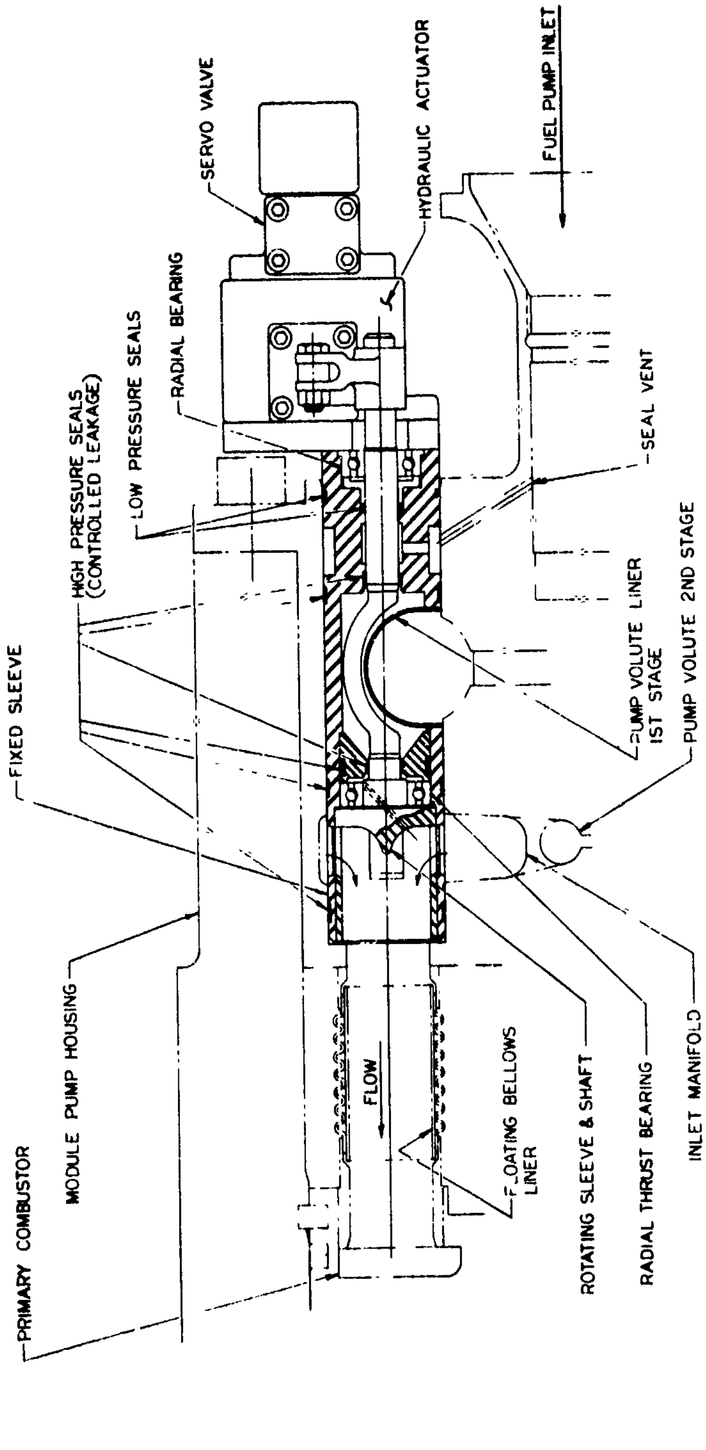
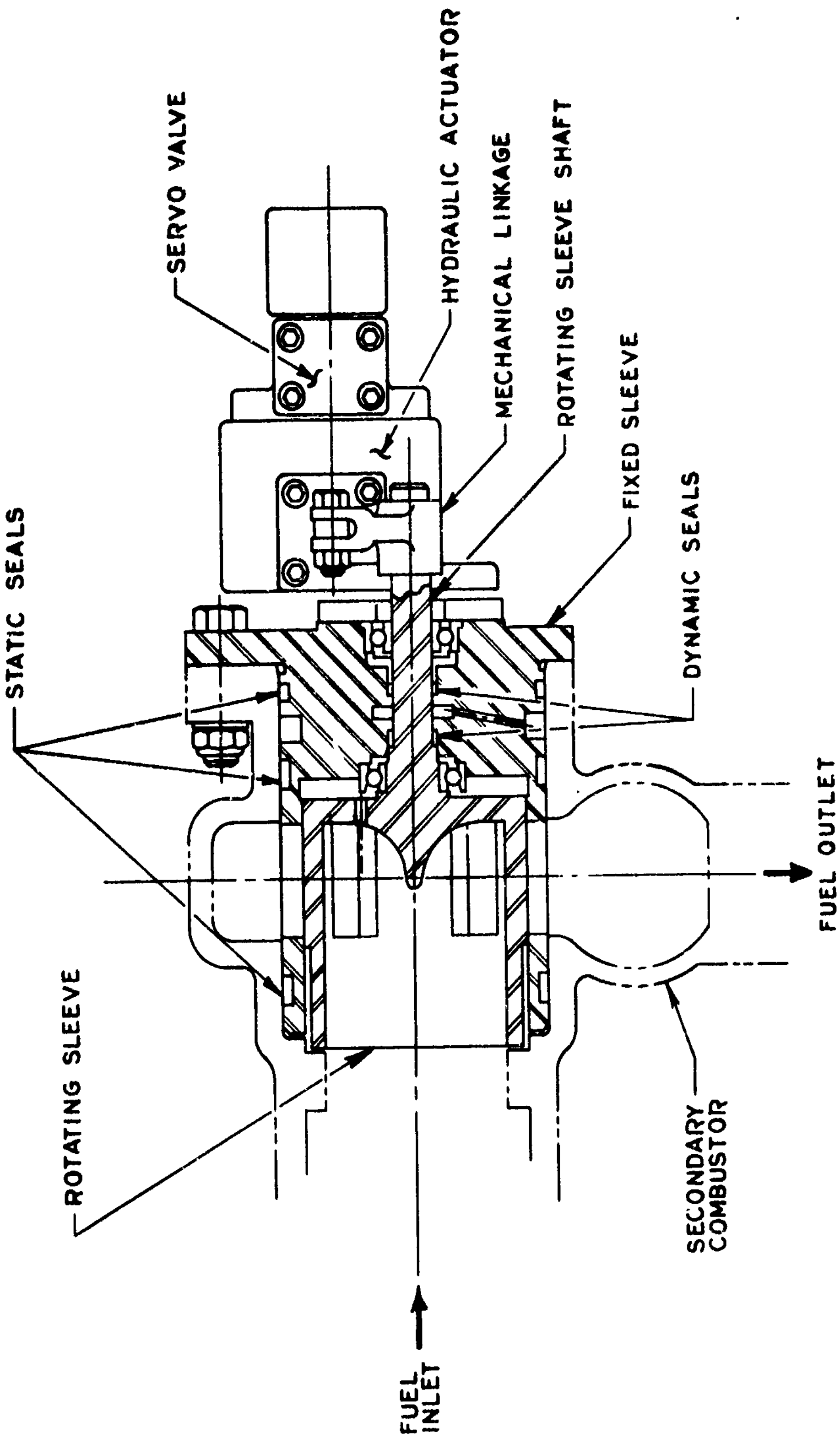
Design Specifications for
Fuel Control Valves
Table I-7.2-1

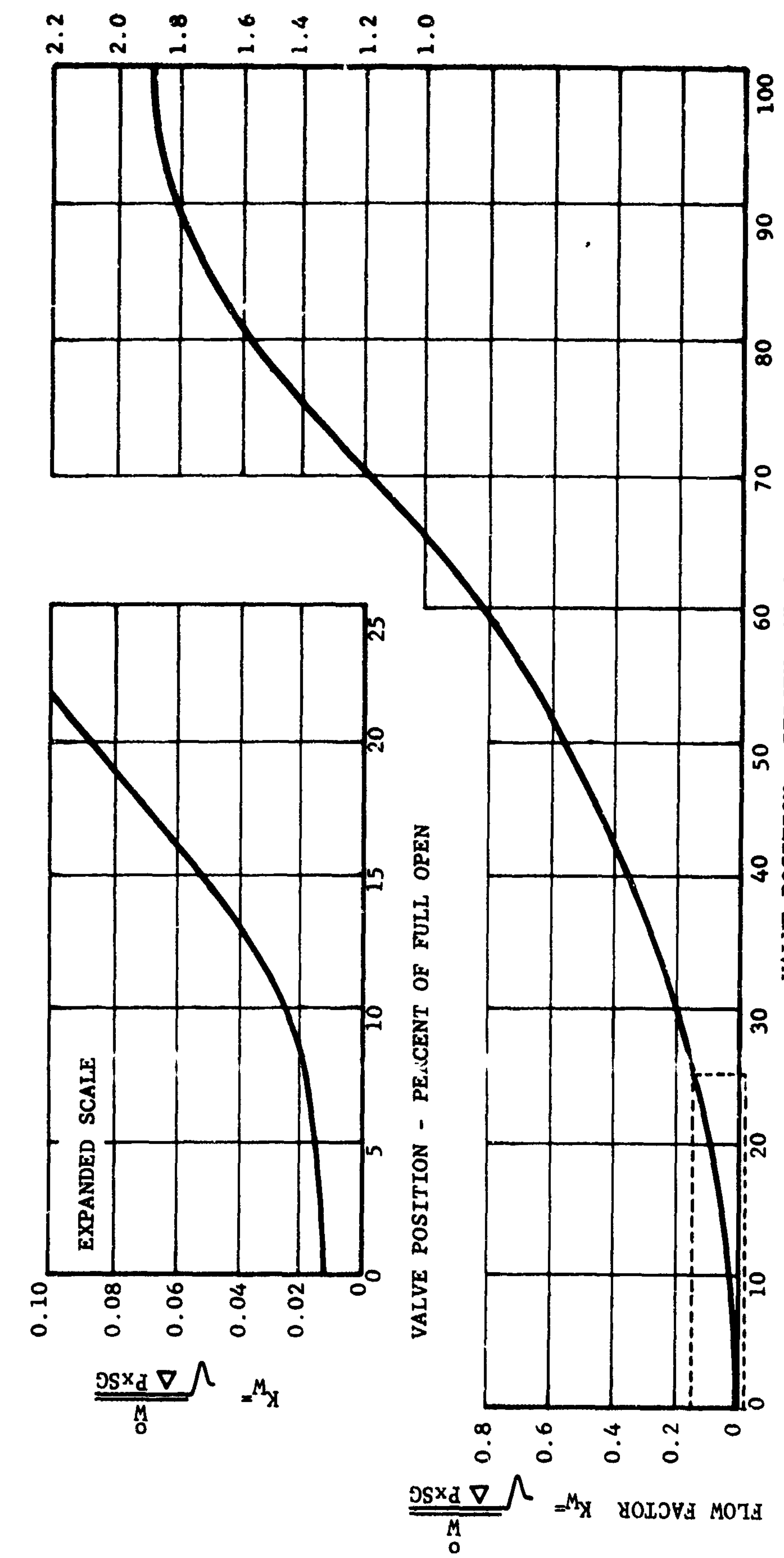


Primary Combustor Fuel Control Valve (Module)

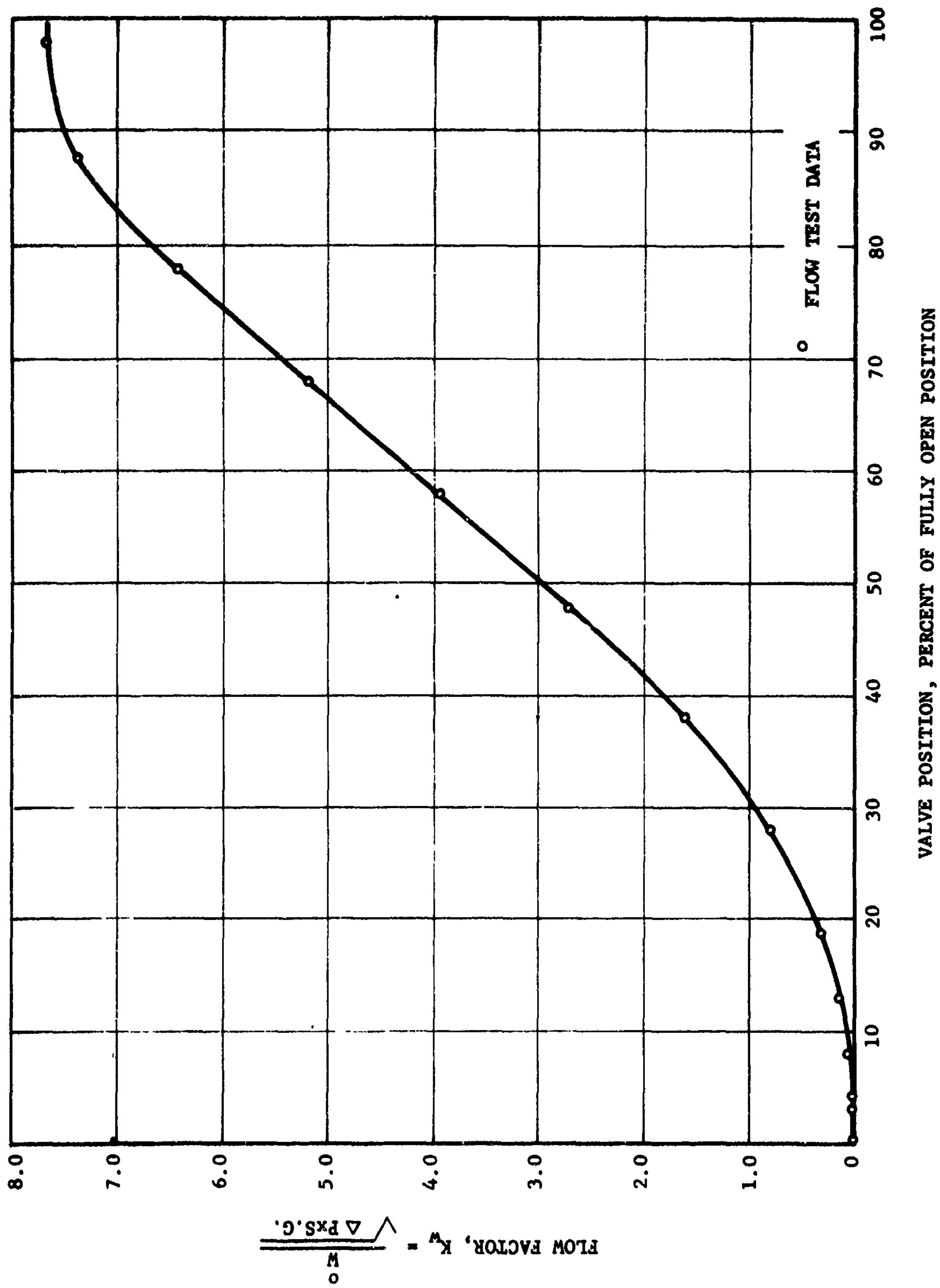


Secondary Combustor Fuel Control Valve (Module)

Figure I-7.1.2-1



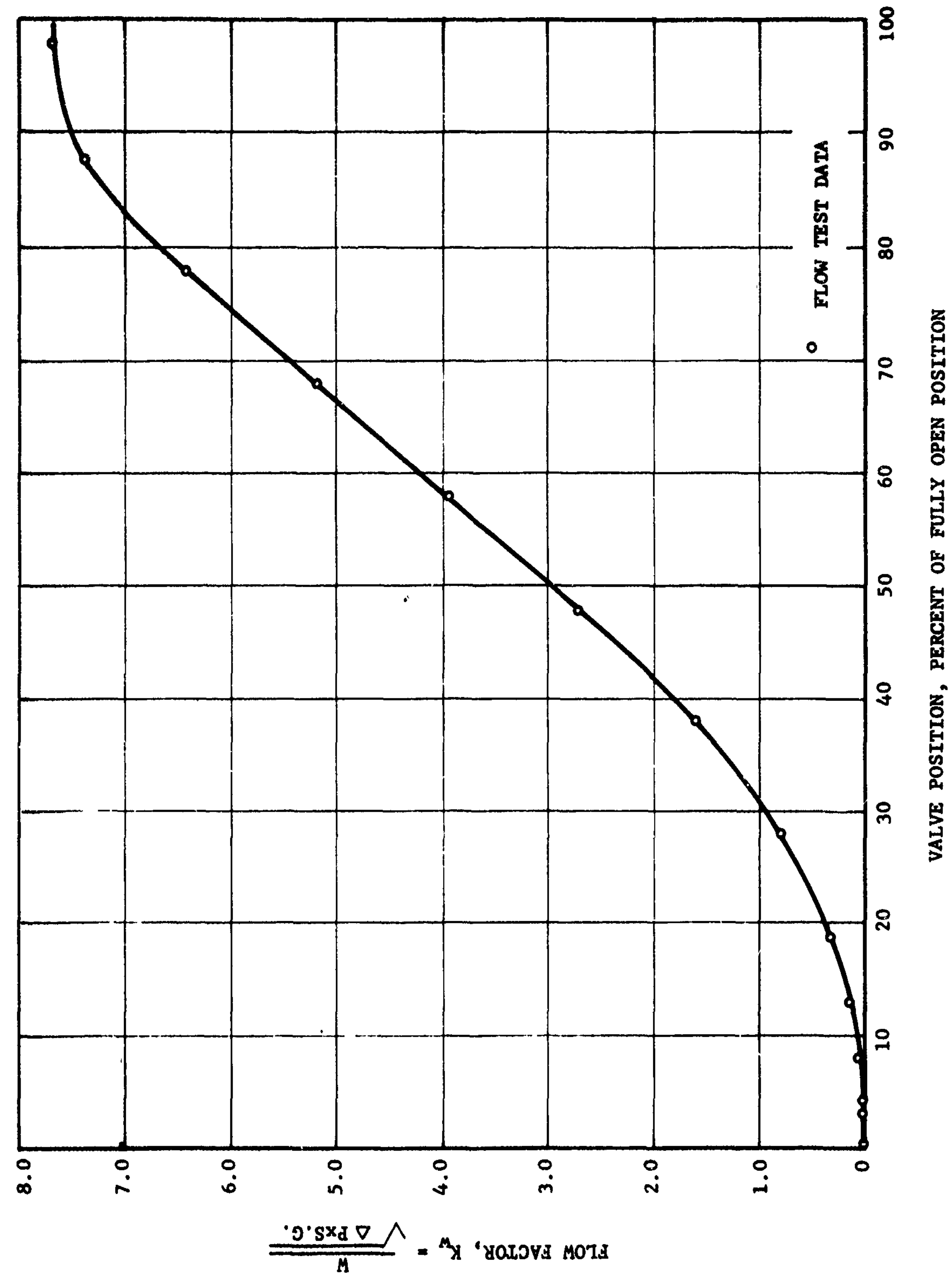
PREDICTED PERFORMANCE, PRIMARY COMBUSTOR FUEL CONTROL VALVE



22 JULY 1966

PREDICTED PERFORMANCE
SECONDARY COMBUSTOR FUEL-CONTROL VALVE

Figure I-7.3.2-1



22 JULY 1966

PREDICTED PERFORMANCE
SECONDARY COMBUSTOR FUEL-CONTROL VALVE

Figure I-7.3.2-1

8.0 VALVES, SUCTION

8.1 DESCRIPTION

The suction valve concept, oxidizer and fuel, is shown in Figure I-8.1-1. The valves are identical in configuration except as shown.

8.2 SPECIFICATIONS

The design specifications and contract work statement requirements for the suction valves are shown in Table I-8.2-1.

8.3 PERFORMANCE

The suction valve hydraulic flow characteristics, K_W versus actuation shaft position, are shown in Figure I-8.3-1

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TABLE I-8.2-1

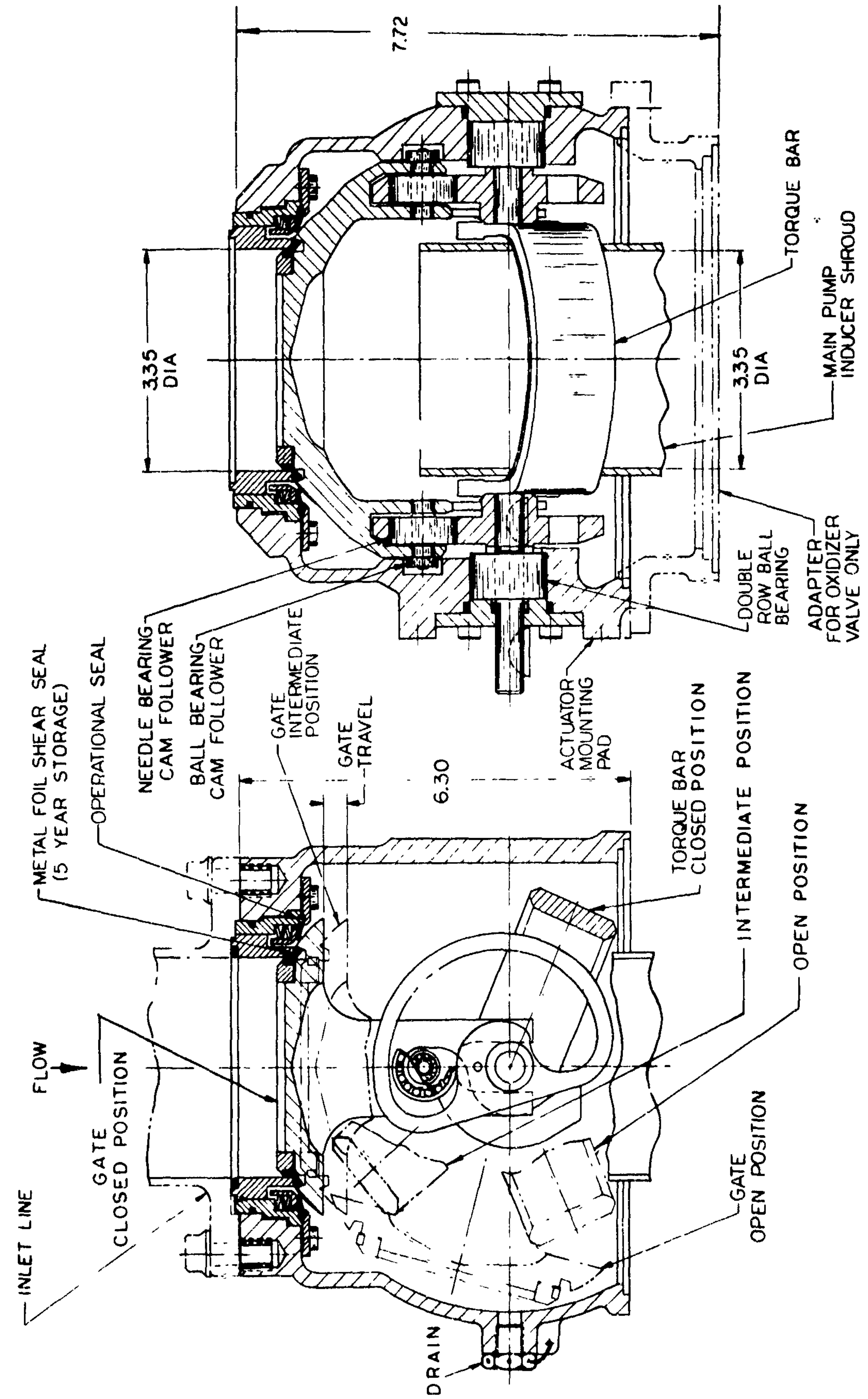
CONTRACT WORK STATEMENT REQUIREMENTS

Parameter	Fuel Suction Valve		Oxidizer Suction Valve	
	Specified	Predicted	Specified	Predicted
Internal Leakage				
Storage (std cc/sec, helium)	$<1 \times 10^{-4}$	$<1 \times 10^{-6}$	$<1 \times 10^{-4}$	$<1 \times 10^{-6}$
Operational (cc/Min)	<1.0	<1.0	<10.0	<1.0
External Leakage				
Storage (std cc/sec, helium)	$<1 \times 10^{-4}$	$<1 \times 10^{-6}$	$<1 \times 10^{-4}$	$<1 \times 10^{-6}$
Operational - shaft only (cc/hr)	<5.0	<5.0	<5.0	<5.0
Response Time Capability				
Opening (sec)	<0.400	<0.350	<0.400	<0.350
Closing (sec)	<0.400	<0.350	<0.400	<0.350
Endurance Cycles after which above Criteria must be met	500	>500	500	>500

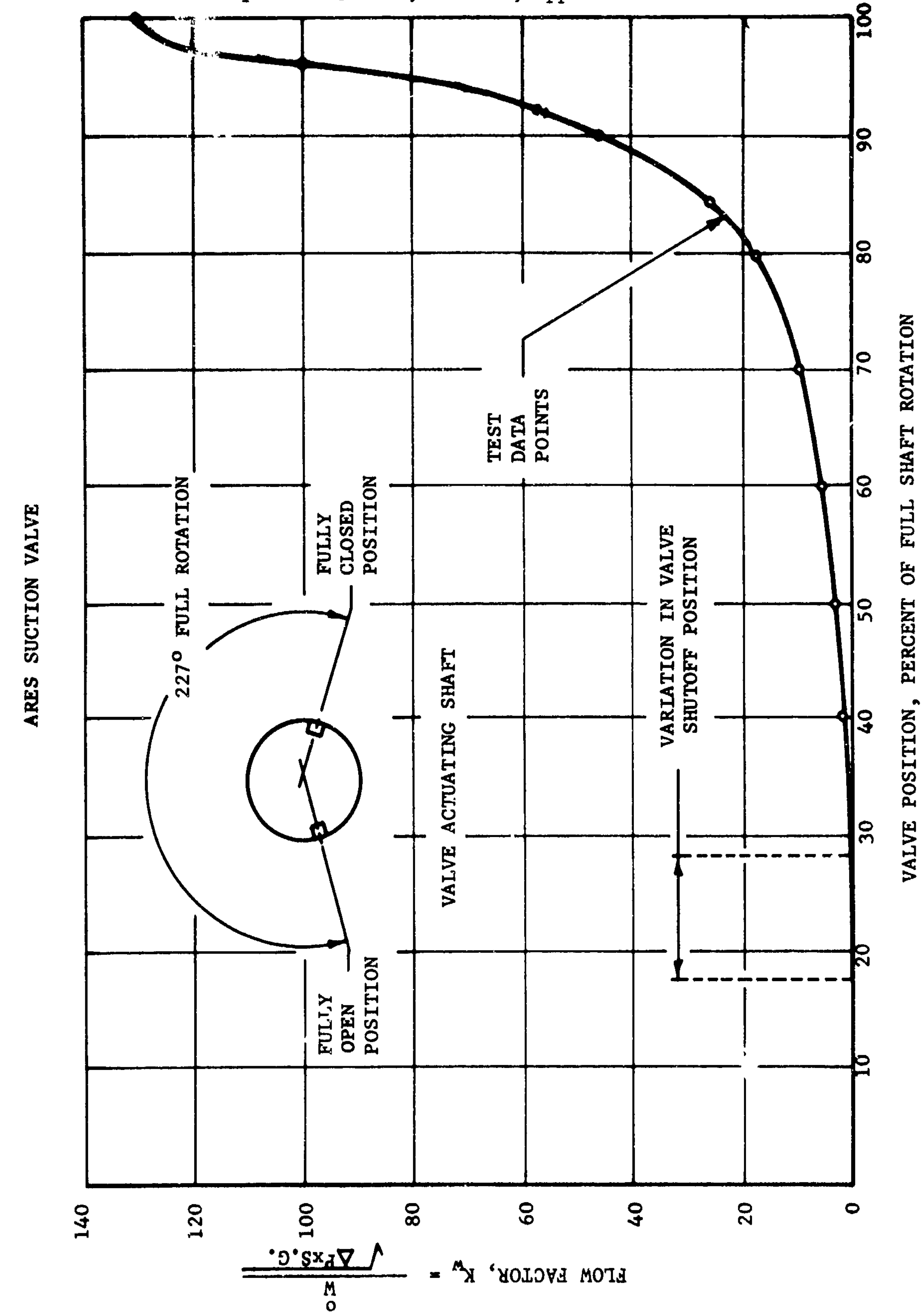
ARES ENGINE FLOW REQUIREMENTS

$$\text{Flow Factor } K_W = \frac{\dot{W}}{\sqrt{\Delta P \times S.G.}}$$

	Fuel Specified	Fuel Predicted	Oxidizer Specified	Oxidizer Predicted
Full open position	>110	120	>120	125
Full closed position	0	0	0	0



Suction Valve
Demonstration Configuration



23 NOVEMBER 1966

FLOW CHARACTERISTICS,
SUCTION VALVE

Figure I-8.3-1

9.0 BACKUP TURBOPUMP ASSEMBLY

9.1 ENGINE MODULE, BACKUP TURBOPUMP CONFIGURATION

9.1.1 Description

The backup turbopump (designated as Conservative Turbopump in the work statement) operates at a speed of 30,000 rpm, compared to the advanced turbopump speed of 40,000 rpm. The description of the engine book for the advanced turbopump assembly are applicable to the backup module. The staged combustion cycle for the backup module is shown in Figure I-9.1.1-1 and it is basically the same as that of the advanced TPA.

A layout of an engine module incorporating the backup turbopump assembly configuration is shown in Figure I.9.1.1-2. This module incorporates the same secondary combustor, suction valves, and fuel control valves as used for the advanced TPA module configuration. The primary combustor is similar but slightly larger in diameter due to the larger turbine wheel.

9.1.2 Pressure Schedule

The module and its subassemblies have been analyzed to establish the internal pressure, flow, and temperature values. These values, as in the case of the advanced TPA module, have been optimized to achieve minimum weight and turbine operating temperatures. The module pressure schedule, based on maximum internal pressure-drop values, and minimum turbopump efficiencies, is shown in Table I-9.1.2-1.

9.1.3 Operating Point

A predicted operating point for the backup TPA module was established using the steady-state mathematical model of the module. The same approach was used as for the advanced TPA module. Results of this analysis, consistent with the pressure schedule above, are given in Table I-9.1.3-1.

9.2 BACKUP TURBOPUMP ASSEMBLY

9.2.1 Turbopump Assembly

The backup turbopump assembly configuration is shown in Figure I-9.2.1-1.

9.2.2 Oxidizer Pump

The oxidizer pump inducer and main stage impeller specifications for design purposes are presented in Table I-9.2.2-1 and I-9.2.2-2, respectively. Predicted overall pump performance is presented in Figure I-9.2.2-1. Predicted cavitating head loss is in Figure I-9.2.2-2.

9.2.3 Fuel Pump

The fuel pump inducer, main stage impeller and second stage impeller specifications are presented in Tables I-9.2.2-1 and I-9.2.2-2. Predicted performance for the main stage is presented in Figure I-9.2.2-1, and for the second stage in Figure I-9.2.2-3. Predicted cavitating head loss is in Figure I-9.2.2-2.

9.2.4 Turbine

The turbine specification is presented in Table I-9.2.4-1. The predicted shaft torque, flow, and power functions are presented in Figures I-9.2.4-1, I-9.2.4-2, and I-9.2.4-3, respectively. The predicted turbine performance map is in Figure I-9.2.4-4.

9.2.5 Power Transmission

The turbopump bearings and power transmission specifications are presented in Tables I-9.2.5-1 and I-9.2.5-2, respectively.

9.2.6 Boost Pump Assembly

The boost pump and hydraulic turbine specifications are presented in Section 4, "Boost Pump Assemblies", and are the same as for the advanced TPA.

Table I-9.1.2-1
ARES MODULE PRESSURE SCHEDULE-BACKUP TPA CONFIGURATION (u)

Pressure, (Total Press. Unless Otherwise Indicated)	Film Cool.	Primary Combustor Turbine Circuit		Secondary Combustor
	← Oxidizer	→	← Fuel	→
Boost Pump Inlet	36.6(NPSH=30 ft)		19.5(NPSH=43 ft)	
Boost Pump Discharge	260		150	
Suction Line and Valve ΔP	80		50	
Main Pump Inlet	180		100	
Main Pump Discharge	5900		3750	
2nd Stage Fuel Pump Inlet			3600	
2nd Stage Fuel Pump Discharge			5750	
Manifold ΔP	125	0	100	100
Cooling Jacket ΔP		850		
Cooling Jacket Exit		5050		
Control Valve ΔP			500	350
Manifold ΔP		50	50	
Balancing Orifice ΔP	725			
PC Injector Inlet		5000	5100	
PC Injector ΔP		300	400	
PC Injector Face		4700		
ΔP to Turbine Inlet		125		
Turbine Inlet		4575		
Turbine ΔP Total to Static		1590		
Turbine Pressure Ratio Total to Static		1.53		
Turbine Exit Static Pressure		2985		
Turbine Exit Total Pressure		3035		
ΔP to SC Injector	50	25		100
SC Injector Inlet		3010		3200
SC Injector ΔP		125		315
Film Cooling ΔP	2200			
SC Injector Face		2885		
ΔP to SC Plenum		85		
SC Chamber Pressure Ratio		1.03		
SC Chamber (P_c)		2800		

TABLE I-9.2.2-1

BACKUP TPA MAIN STAGE
INDUCER DESIGN SPECIFICATION (u)

	HYDRAULIC DESIGN POINT	MAXIMUM STRESS CONDITION
Temperature - °F	77	77
Specific Weight - lb/ft^3		
OSMI	89.5	
FSMI	56.1	
Vapor Pressure - psia		
P_{OVMI}	18.0	
P_{FVMI}	2.8	
Speed - rpm	30,000	33,000
Head Rise - Ft		
H_{ODMI}	451	546
H_{FDMI}	346	419
Flow Rate - gpm		
Q_{OSMI}	1422	1565
Q_{FSMI}	924	1016
Efficiency - % (minimum)		
OMI	50	
FMI	45	
Net Positive Suction Heat - Ft.		
$NPSH_{OSMI}$	262	
$NPSH_{FSMI}$	228	
Shaft Horsepower - HP		
HP_{OMI}	465	619
HP_{FMI}	161	214
Inducer Total Discharge Pressure - PSIA		
P_{ODMI}	461	558
P_{FDMI}	226	273

Table I-9.2.2-1

TABLE I-9.2.2-2

BACKUP TPA STAGE IMPELLER
DESIGN SPECIFICATION (u)

	HYDRAULIC DESIGN POINT	MAXIMUM STRESS CONDITION
Temperature - °F	77	77
Specific Weight - lb/ft^3		
OSM	89.5	89.5
FSM-1	56.1	56.1
Vapor Pressure - psia		
P_{OVM}	18.0	
P_{FVM-1}	2.8	
Speed - rpm	30,000	33,000
Head Rise - Ft. (excludes inducer)		
H_{ODM}	8698	10,500
H_{FDM-1}	9139	11,090
H_{FDM-2}	5350	6475
Flow Rate - gpm		
Q_{OSM}	1430	1574
Q_{FSM-1}	942	1036
Q_{FSM-2}	167	184
Efficiency - % (minimum)		
OM	68	68
FM-1	63	63
FM-2	55	55
NPSH-ft (minimum)		
$NPSH_{OSM}$	660	
$NPSH_{FSM-1}$	458	
SHAFT POWER - HP		
SHP_{OM}	6640	8840
SHP_{FM-1}	3100	4130
SHP_{FM-2}	369	491
PUMP DISCHARGE PRESSURE - PSIA		
P_{ODM}	5871	7060
P_{FDM-1}	3786	4560
P_{FDM-2}	5718	6920

Table I-9.1.3-1

ARES MODULE TARGET OPERATING POINT
BACKUP TURBOPUMP CONFIGURATION (u)

The Parameters in this table with the conditions noted below define the Target Operating Point for the Backup Module. This is a predicted target module/component operating point based on predicted component performance, and shall not be used as a design specification.

Assumptions for Backup Target Operating Point	Reference	
1. Cycle configuration: Backup (inline) turbopump with oxidizer film and regeneratively cooled secondary combustor	Figure 9.1.1-1, dated 22 December 1965	
2. Balance for target performance: Same as advanced module	Paragraph 2.3.1	
3. Secondary combustor performance vs oxidizer film coolant:	Figure 2.7-1, dated 10 March 1967	
Same as advanced module. Nominal $\hat{W}_{OFC}$ reduced to 18 lb/sec		
4. Turbopump predicted performance:	**Figure**	**Date**
Oxidizer Pump, new design point, no change in efficiency	9.2.2-1 9.2.2-2	10 Mar 1967 10 Mar 1967
Fuel Pump 1st Stage, new design point and reduced efficiency (used minimum)	9.2.2-1 9.2.2-2	10 Mar 1967 10 Mar 1967
Fuel Pump 2nd Stage, new design point and reduced efficiency (used minimum)	9.2.2-3	10 Mar 1967
Turbine, new performance curves. Used minimum efficiency	9.2.4-1 9.2.4-2 9.2.4-3 9.2.4-4	24 Feb 1966 " " "
Boost Pumps Boost pumps now same as for advanced module	4.1.3-1 4.1.3-2	24 May 1966 10 Mar 1967

Table I-9.1.3-1 (cont.)

Assumptions for Backup Target Operating Poing	Reference Figure	Date
Boost Pump Turbines Boost turbines now same as for advanced module	4.1.3-3 4.2.3-1	10 Mar 1967 10 Mar 1967
5. Suction pressures:		
a. Boost pump suction pressures set for minimum NPSH.	Paragraph 2.3.1	
b. Main pump suctions set for suction specific speeds similar to advanced module		
6. Seal flows: In the backup module, the only seal flow treated as as an engine flow (and excluded from turbopump internal losses) is the turbine seal oxidizer flow. It is assumed to be 2.3 lb/sec from the oxidizer pump discharge to the turbine exhaust.	Similar to $\hat{W}_{OBOS-1}$ in the advanced module. See Figure 2.6-1.	
7. Following improvements in backup module computer program:		
a. Added formulae for computing temperature rise through pumps, hydraulic turbine, and regenerative cooling tubes.		
b. Computed local propellant density as a function of internal pressure and temperature.		
8. Fluid resistance allocations: Passage resistances conformed to previous pressure schedule except for following changes:	Table 9.1.2-1, dated 10 March 1967	

Table I-9.1.3-1 (cont.)

Assumptions for Backup Target Operating Point	Reference
a. Suction line ΔP's were increased.	
b. Cooling jacket and injector resistances adjusted to conform with advanced module.	Table 2.6-2, dated 24 Aug 1966
9. Boost turbine orifice ΔP's required to balance engine are substantially larger than in advanced module, since boost pumps are run at a lower speed in backup module.	

Table I-9.1.3-1 (cont.)

Module Assembly

Parameter	Symbol	Units	Value
Thrust	F	lb	100,000
Specific Impulse (Sea Level)	I_s	sec	285
Mixture Ratio (1)	M.R	-	2.37
Efficiency, Specific Impulse	ηI_s	%	91.6
Oxidizer Weight Flow	$\dot{W}_{OSBP}$	lb/sec	246.9
Fuel Weight Flow	$\dot{W}_{FSBP}$	lb/sec	104.0
Total Weight Flow	$\dot{W}_T$	lb/sec	350.9
Fuel Suction Pressure	P_{FSBP}	psia	19.5
Oxidizer Suction Pressure	P_{OSBP}	psia	36.3

Secondary Combustor

Parameter	Symbol	Units	Value
Chamber Pressure, Plenum	P_{SC}	psia	2,800
Combustion Efficiency	η_c	-	96.3
Nozzle Efficiency	N	-	95.2
Mixture Ratio, Injector	$M.R._{SC}$	-	2.20
Fuel Flow, Injector	$\dot{W}_{FSC}$	lb/sec	84.2
Gas Weight Flow to Injector	$\dot{W}_{GSC}$	lb/sec	248.7

(1) Includes film cooling

Table I-9.1.3-1 (cont.)

Secondary Combustor (cont.)

Parameter	Symbol	Units	Value
Oxidizer Flow Regen. Cooling	$\dot{W}_{ORG}$	lb/sec	226.6
Oxidizer Film Cooling	$\dot{W}_{OFC}$	lb/sec	18.0
Maximum Regen. Coolant Capability	ϕ_{SC}	Btu/in.^{2} sec	15.6
Throat Area	A_{TSC}	in.^{2}	21.35
Area Ratio	ε	-	20
Pressure Ratio (Sea Level)	R_{PSC}	-	190.5
Characteristic Length	L^*_{SC}	in.	40
Temperature Rise Regen. Coolant	ΔT_{ORG}	°F	119
Pressure Drop Regen. Coolant Tube	ΔP_{ORG}	psi	850
Characteristic Velocity (2)	c^*_{SC}	ft/sec	5481
Thrust Coefficient (2)	C_F	-	1.673

Primary Combustor

Parameter	Symbol	Units	Value
Chamber Pressure, Injector Face	P_{PC}	psia	4,698
Gas Temperature	T_{PC}	°F	1,236
Mixture Ratio	MR_{PC}	-	11.40
Oxidizer Flow	$\dot{W}_{OPC}$	lb/sec	226.6
Fuel Flow	$\dot{W}_{FPC}$	lb/sec	19.9
Propellant Total Flow	$\dot{W}_{TI}$	lb/sec	246.5
Characteristic Velocity	c^*_{PC}	ft/sec	2,417
Specific Heat Ratio	k_{PC}	-	1.2571
Molecular Weight	M_{PC}	lb/mole	33.2

(2) Based on geometric throat area and engine total flow.

Table I-9.1.3-1 (cont.)

Main Turbopump - Pumps

Parameter	Symbol Fuel	Symbol Oxidizer	Units	Value Fuel	Value Oxidizer
Propellant Temperature	T_{FSM-1}	T_{OSM}	°F	80.5	82.5
Propellant Temperature	T_{FSM-2}			91.7	
Propellant Specific Weight	γ_{FSM-1}	γ_{OSM}	lb/ft³	56.0	89.2
Propellant Specific Weight	γ_{FSM-2}			56.5	
Shaft Speed	N_T		rpm	30,230	30,230
Total Suction Pressure	P_{FSM-1}	P_{OSM}	psia	97	182
Total Suction Pressure	P_{FSM-2}		psia	3,586	
Net Positive Suction Head	$NPSH_{FSM}$	$NPSH_{OSM}$	ft	242	262
Total Discharge Pressure	P_{FDM-1}	P_{ODM}	psia	3,741	5,933
Total Discharge Pressure	P_{FDM-2}		psia	5,902	
Head (Noncavitating)	H_{FDM-1}	H_{ODM}	ft	9,369	9,286
Head	H_{FDM-2}		ft	5,920	
Weight Flow	$\dot{W}_{FSM-1}$	$\dot{W}_{OSM}$	lb/sec	121.0	284.9
Weight Flow	$\dot{W}_{FSM-2}$		lb/sec	19.9	
Volume Flow	Q_{FSM-1}	Q_{OSM}	gpm	970	1,434
Volume Flow	Q_{FSM-2}		gpm	158	
Ratio Pump to engine flow	$R_{\dot{W}FSM-1}$	$R_{\dot{W}OSM}$	-		
Ratio Q/N	Q_{FSM-1}/N_T	Q_{OSM}/N_T	gpm/rpm	.0321	.0474
Ratio Q/N	Q_{FSM-2}/N_T		gpm/rpm	.0052	

Table I-9.1.3-1 (cont.)

Main Turbopump - Pumps (cont.)

Parameter	Symbol Fuel	Symbol Oxidizer	Units	Value Fuel	Value Oxidizer
Specific Speed	N_{SFM-1}	N_{SOM}	$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	989	1,210
Specific Speed	N_{SFM-2}		$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	563	
Ratio H/N^2 (Noncavitating)	H_{FDM-1}/N_T^2	H_{ODM}/N_T^2	ft/rpm^2	10.25	10.16
Ratio H/N^2	H_{FDM-2}/N_T^2		ft/rpm^2	6.48	
Efficiency	η_{FM-1}	η_{OM}	%	62.8	68.0
Efficiency	η_{FM-2}		%	54.9	
Shaft Power	SHP_{FM-1}	SHP_{OM}	hp	3,282	7,075
Shaft Power	SHP_{FM-2}		hp	390	
Suction Specific Speed	S_{FM-1}	S_{OM}	$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	15,330	17,600
Suction Specific Speed	S_{FM-2}		$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	406	

Table I-9.1.3-1 (cont.)

Main Turbopump - Turbine

Parameter	Symbol	Units	Value
Pressure, Inlet Total	P_{TIT}	psia	4,571
Temperature, Inlet Total	T_{TIT}	°F	1,236
Pressure Ratio, total to static	R_{PT}	-	1.528
Static Back Pressure	P_{TES}	psia	2,992
Temperature, exit total	T_{TET}	°F	1,131
Gas Flow	$\dot{W}_{TI}$	lb/sec	246.5
Shaft Speed	N_T	rpm	30,230
Shaft Power	SHP_T	hp	10,747
Efficiency, turbine	η_T	%	74.8

Table I-9.1.3-1 (cont.)

Boost Pump - Pump

Parameter	Symbol Fuel	Symbol Oxidizer	Units	Value Fuel	Value Oxidizer
Propellant Temperature	T_{FSBP}	T_{OSBP}	°F	77	77
Propellant Specific Weight	γ_{FSBP}	γ_{OSBP}	lb/ft^3	56.1	89.5
Total Suction Pressure	P_{FSBP}	P_{OSBP}	psia	19.5	36.3
Net Positive Suction Head	$NPSH_{FSBP}$	$NPSH_{OSBP}$	ft	43.0	30.0
Shaft Speed	N_{FTBP}	N_{OTBP}	rpm	7,621	7,563
Total Discharge Pressure	P_{FDBP}	P_{ODBP}	psia	150	262
Head (Noncavitating)	H_{FDBP}	H_{ODBP}	ft	334	363
Weight Flow	$\dot{W}_{FSBP}$	$\dot{W}_{OSBP}$	lb/sec	104.0	246.9
Volume Flow	Q_{FSBP}	Q_{OSBP}	gpm	832	1,238
Ratio Q/N	Q_{FS}/N_{FTBP}	Q_{OS}/N_{OTBP}	gpm/rpm	0.109	0.164
Specific Speed	N_{SFBP}	N_{SOBP}	$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	2,815	3,197
Ratio H/N^2 (Noncavitating)	$\frac{H_{FDBP}}{N_{FTBP}^2}$	$\frac{H_{ODBP}}{N_{OTBP}^2}$	$\frac{ft}{rpm^2}$	$5.75x10^{-6}$	$6.35x10^{-6}$
Efficiency, Pump	η_{FBP}	η_{OBP}	%	64.2	64.4
Shaft Power	SHP_{FBP}	SHP_{OBP}	hp	98	253
Suction Specific Speed	S_{FBP}	S_{OBP}	$\frac{rpm\ gpm^{1/2}}{ft^{3/4}}$	13,090	20,760

Table I-9.1.3-1 (cont.)

Boost Pump - Hydraulic Turbine

Parameter	Symbol Fuel	Symbol Oxidizer	Units	Value Fuel	Value Oxidizer
Pressure, Inlet Total	P_{TITFBP}	P_{TITOBP}	psia	2,997	4,833
Temperature Inlet Total	T_{TITFBP}	T_{TITOBP}	°F	90.8	97.9
ΔPressure	ΔP_{TFBP}	ΔP_{TOBP}	psi	3,888	4,621
Static Back Pressure	P_{TEFBP}	P_{TEOBP}	psia	109	212
Flow, Turbine Drive	$\dot{W}_{FTBP}$	$\dot{W}_{OTBP}$	lb/sec	17.0	38.1
Shaft Speed	N_{FTBP}	N_{OTBP}	rpm	7,620	7,560
Shaft Power	SHP_{FTBP}	SHP_{OTBP}	hp	98	253
Efficiency, Turbine	η_{FTBP}	η_{OTBP}	%	43.2	50.5

TABLE I-9.2.4-1

BACKUP TPA MAIN STAGE TURBINE
DESIGN SPECIFICATION (U)

	AERODYNAMIC DESIGN PC	MAXIMUM STRESS CONDITION
Shaft power - HP	11,000	14,625
Gas flow rate - lb/sec	239	
Gas inlet total pressure - psia	4,650	4,650
Gas exit static pressure - psia	3,100	
Gas, inlet total temperature - °F	1235	1,500
Shaft speed - rpm	30,000	33,000
Efficiency - % (minimum)	75	
Specific heat ratio	1.257	
Gas constant $\frac{\text{ft-lb}}{\text{lb. °R}}$	46.1	
M.R.	11.3	

TABLE I-9.2.5-1

BACKUP TPA BEARING
DESIGN SPECIFICATION

1. Bearing size (series 1000)

   a) Roller (ox. end) — 45 MM

   b) Roller (fuel end) — 35 MM

   c) Ball, duplex set (fuel end) — 40 MM

2. Bearing life, minimum hrs.

   a) Roller (each) — 5

   b) Ball (duplex set) — 4

3. Lubrication flow rates, gpm
   - Roller (oxid. end) — 10.0
   - Roller (fuel end) — 18.0
   - Ball, duplex set (fuel end) — 10.0

4. Bearing coolant temperature rise (approx.) — 20°F/Brg.

5. Misalignment or movement allowable — To be determined

6. Maximum steady-state bearing loads lb:

	STEADY STATE	TRANSIENT
Ball set	50	±1,000
Roller	500	1,000

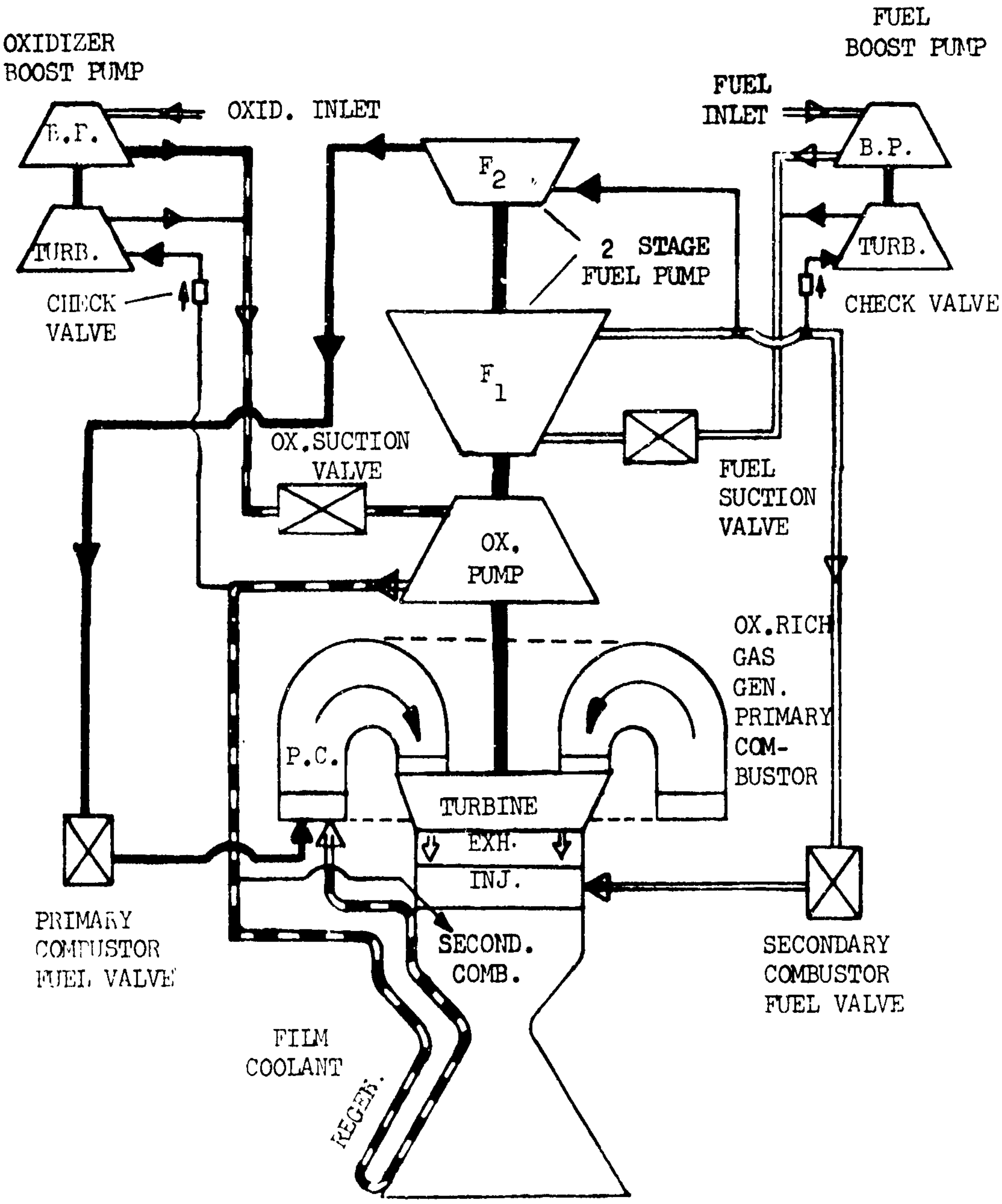
Table I-9.2.5-1

TABLE I-9.2.5-2

BACKUP TPA POWER TRANSMISSION
DESIGN SPECIFICATIONS

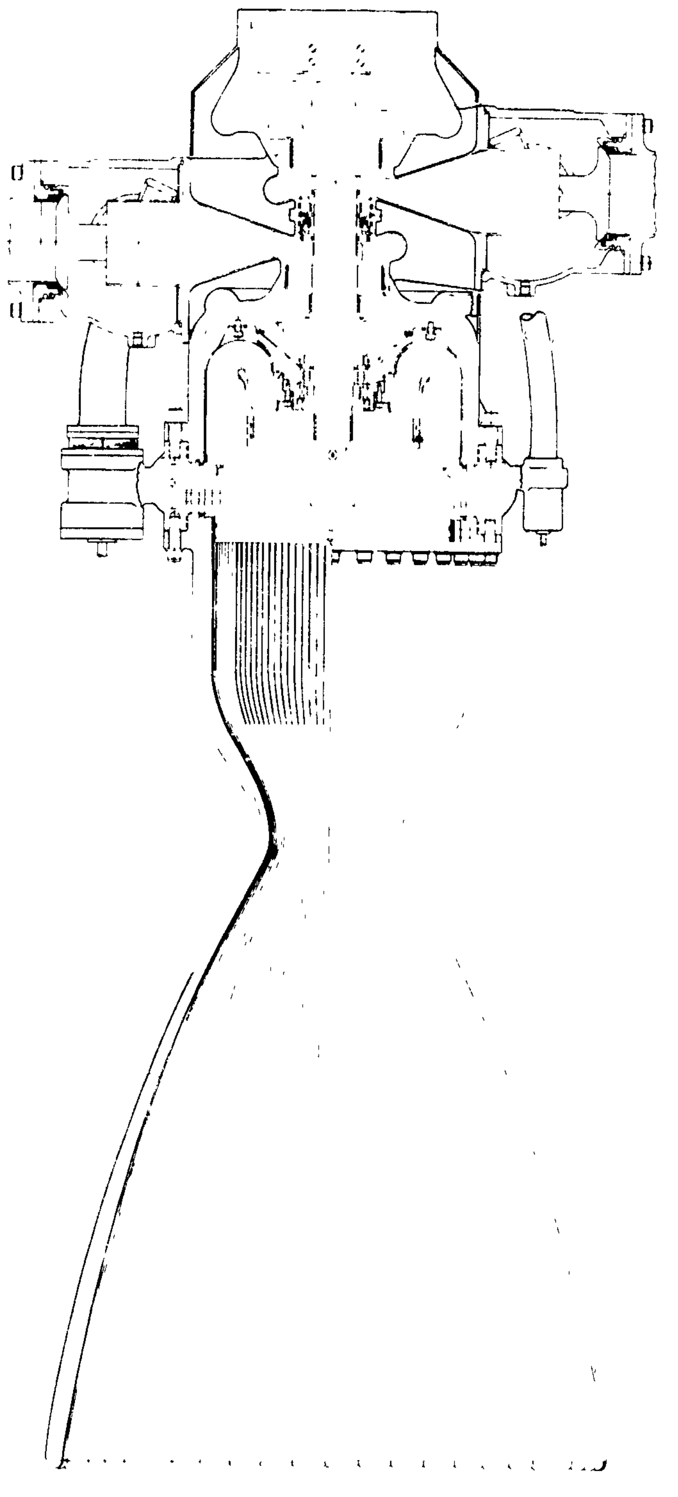
		NOMINAL OPERATING POINT	MAXIMUM STRESS CONDITION
1.	Shaft speed - rpm	30,000	33,000
2.	Shaft torque - ft-lb	1925	2560
3.	Coolant temp. - °F	77	77
4.	Coolant properties @ 77°F		
	Specific heat, Cp		
	N_2O_4	.37	.37
	A-50	.69	.69
	Density - lb/ft^3		
	oxidizer	89.5	89.5
	fuel	56.1	56.1
5.	Minimum critical speed - rpm	42,000	42,000
6.	Vehicle vertical acceleration - ft/sec^2		10 g's
	Acceleration, perpendicular to thrust		5 g's
7.	Maximum TPA rotational acceleration - rpm/sec		60,000

Table I-9.2.5-2



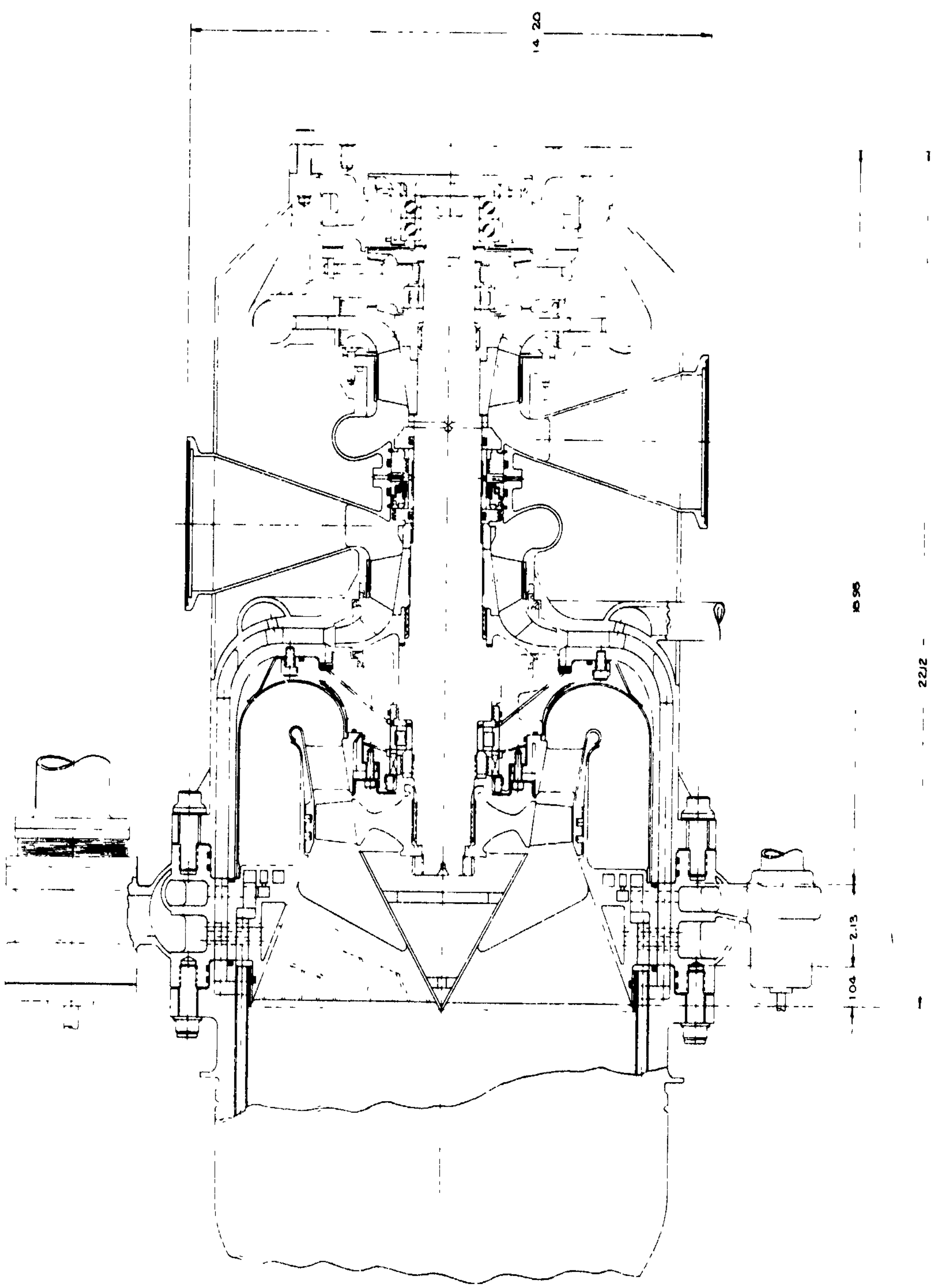
ARES System Staged Combustion Cycle (u)
Backup Turbopump Configuration

22 December 1965 Figure I-9.1.1-1



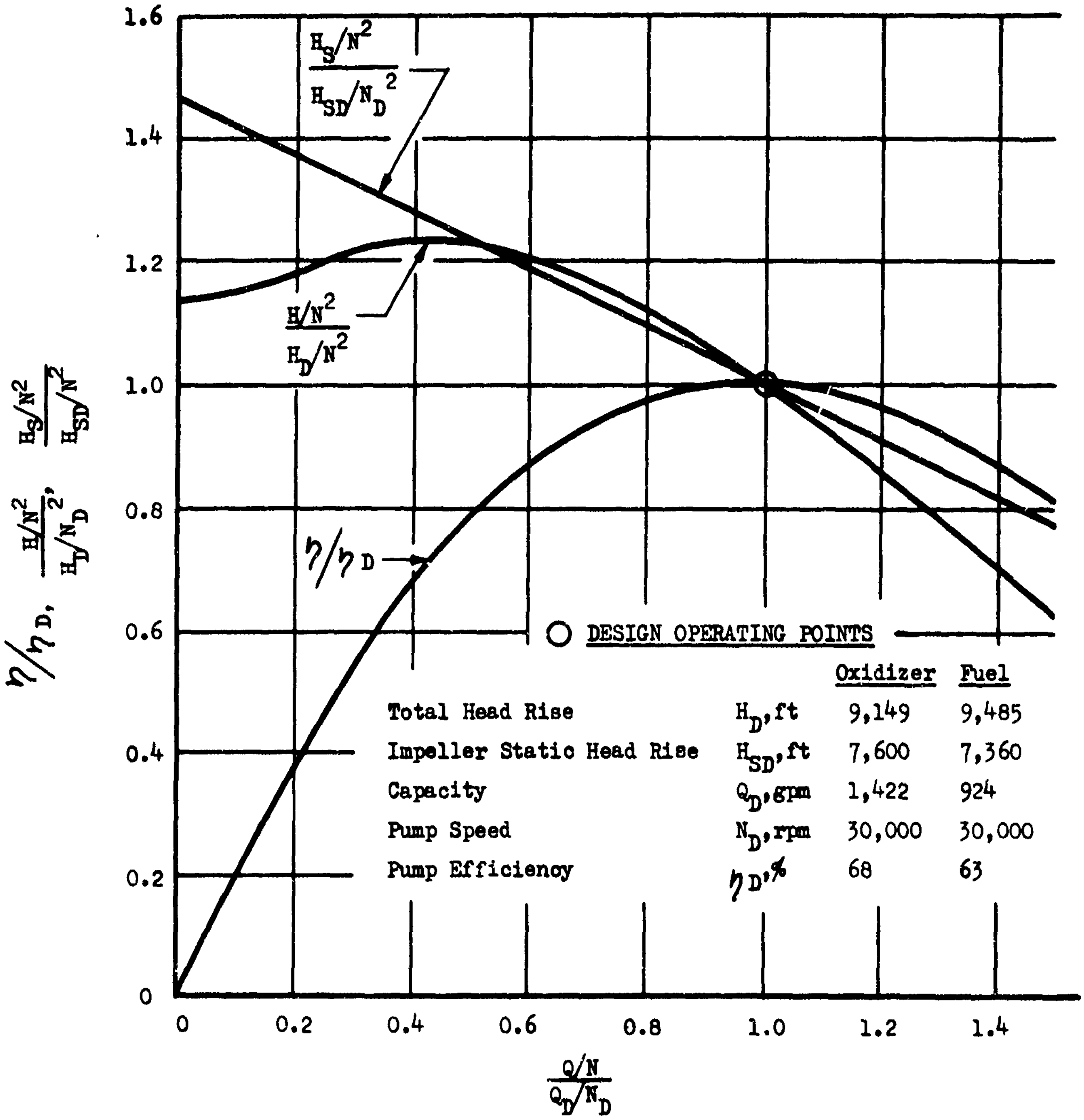
ARES Module, Backup Turbopump Configuration (u)

Figure I-9-1.1-2



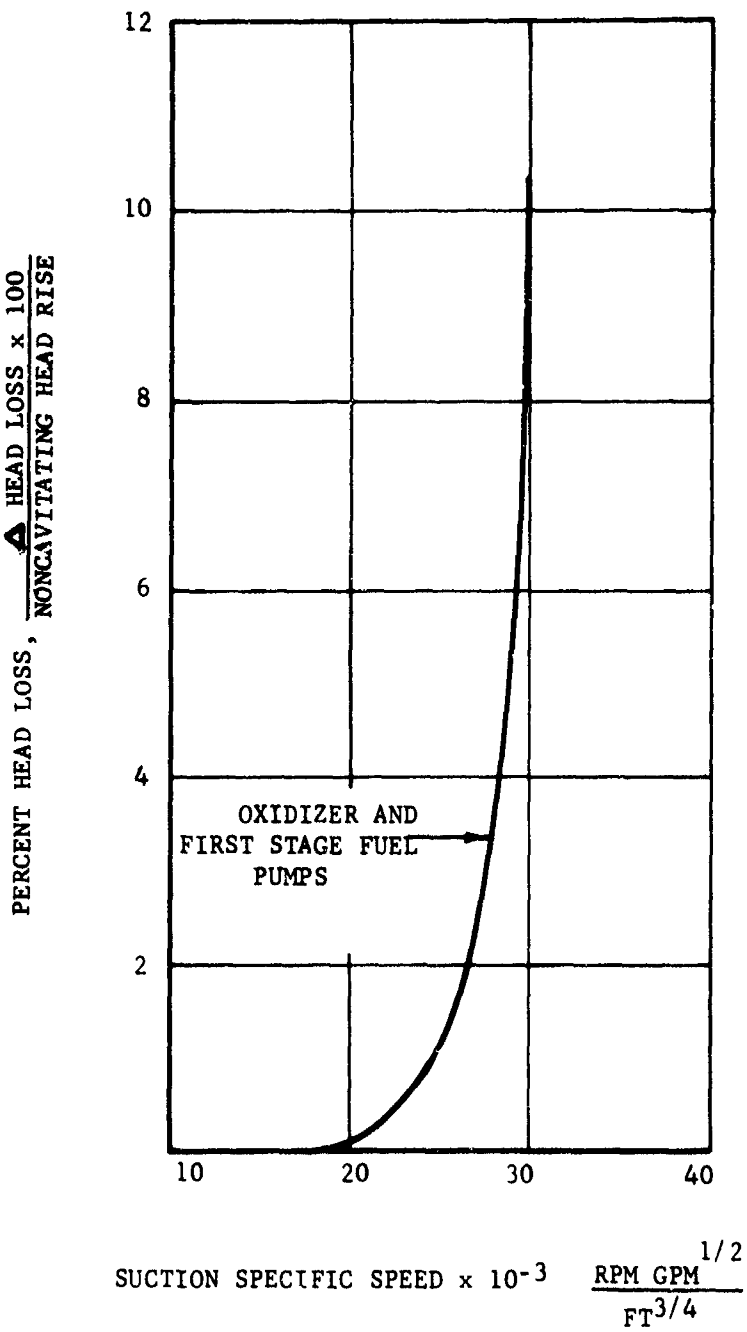
Backup Turbopump Assemblv (u)

Figure I-9.2.1-1



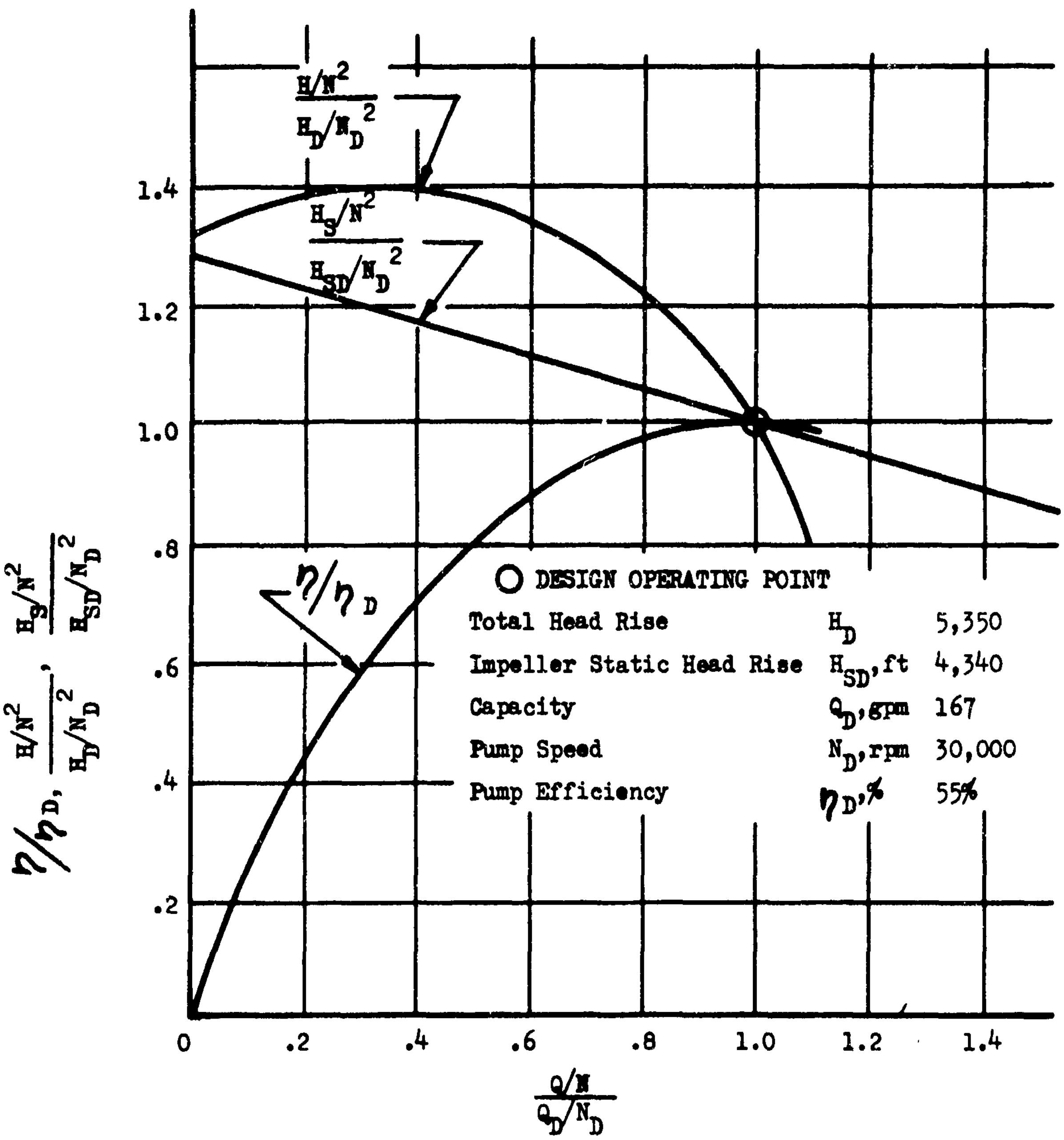
Predicted Noncavitating Performance,
Main-Stage Pumps, Backup Turbopump (u)

10 March 1967 Figure I-9.2.2.-1



Predicted Cavitating Head Loss,
Main Stage Pumps, Backup Configuration

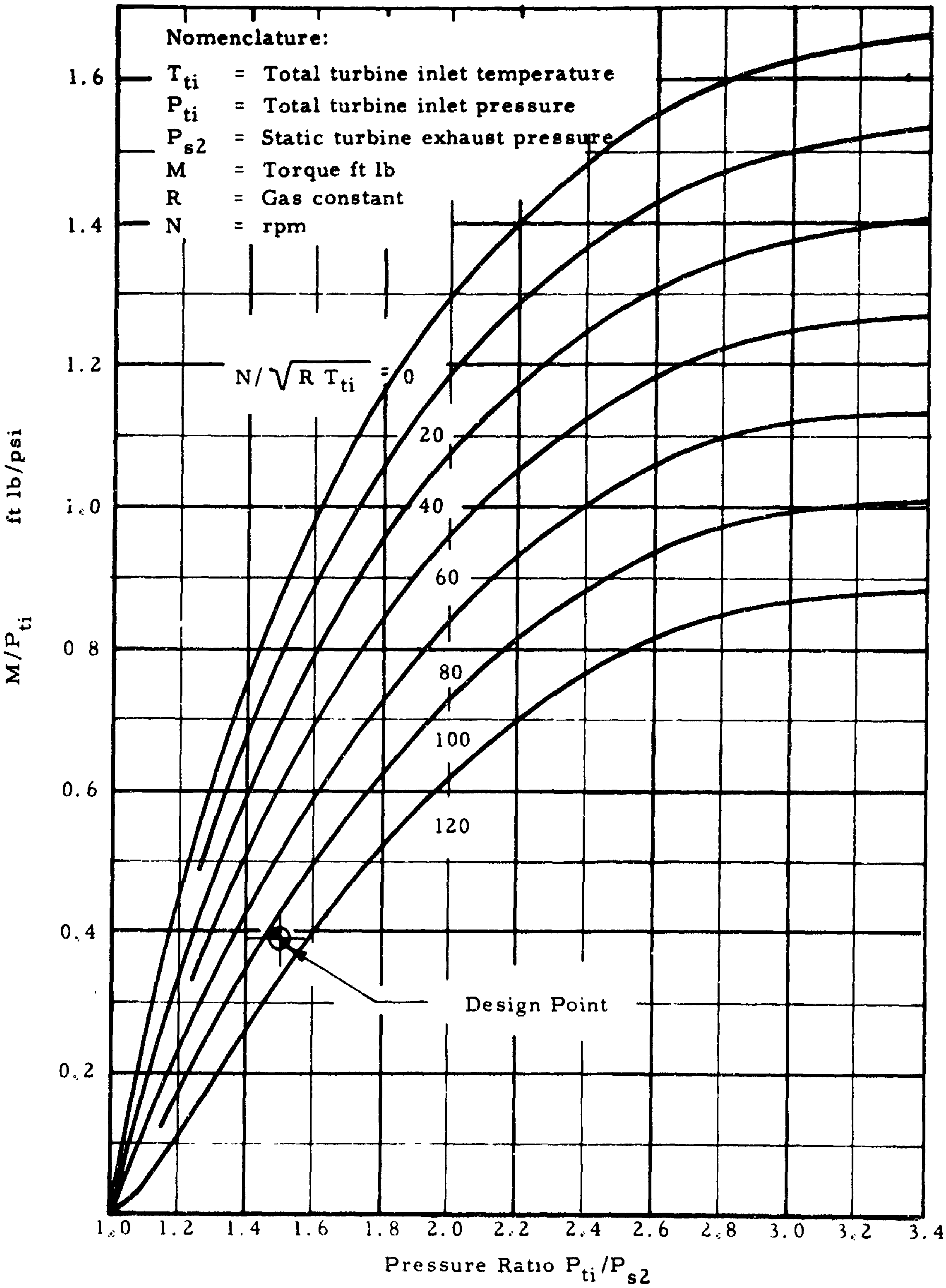
Figure I-9.2.2-2



Predicted Noncavitating Performance, Second-Stage Fuel Pump, Backup Turbopump (u)

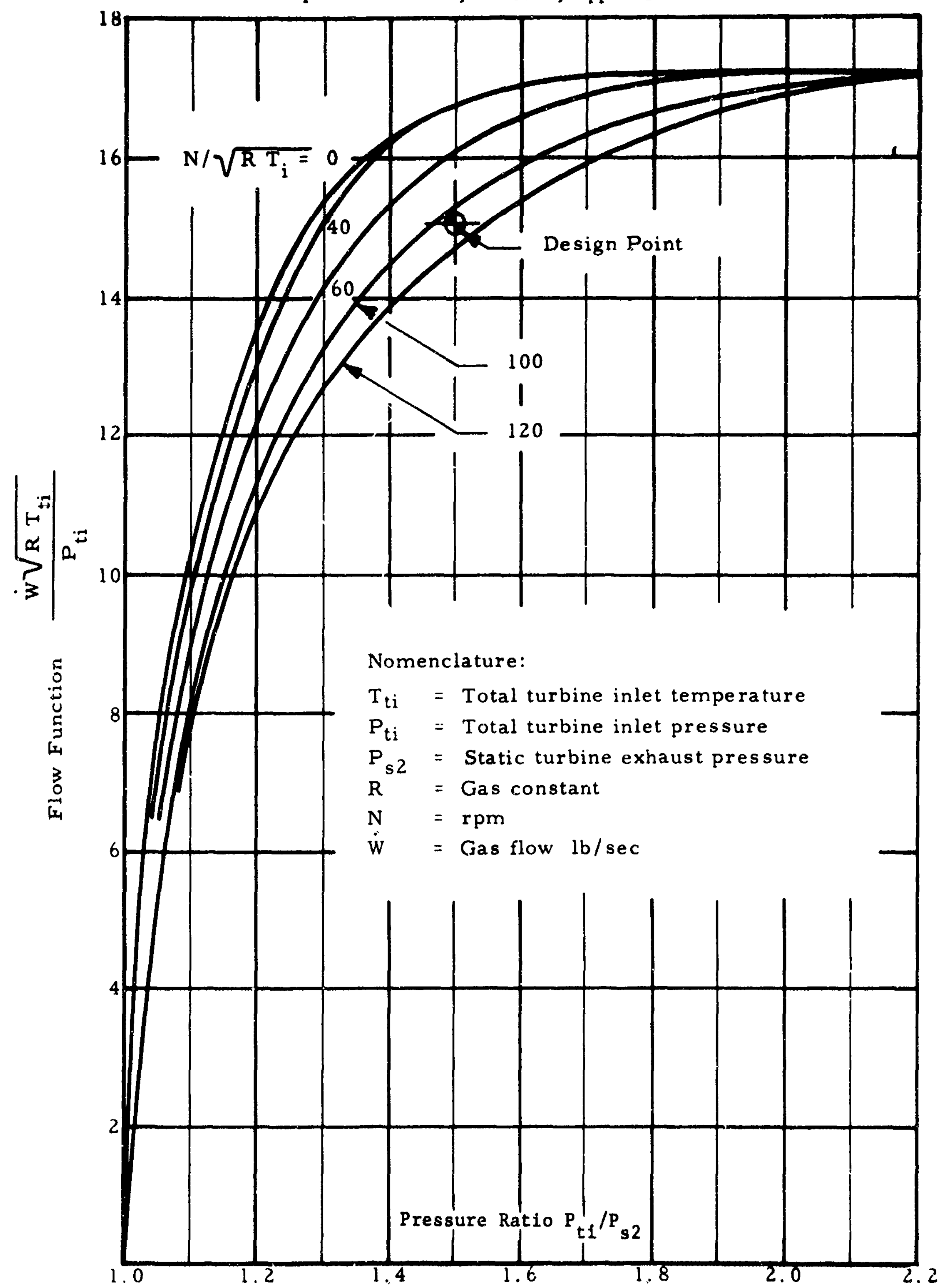
10 March 1967

Figure I-9.2.2-3

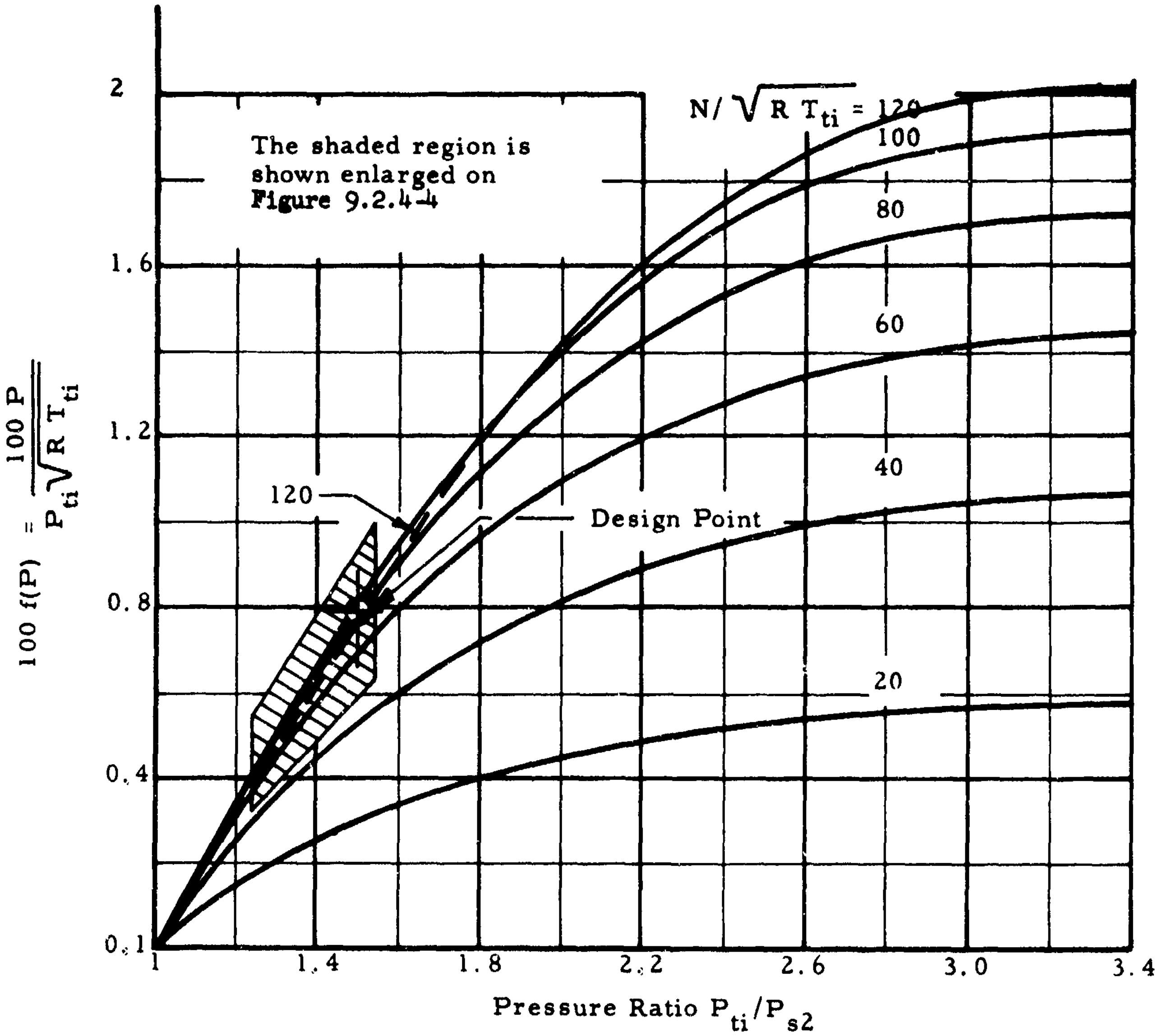


Predicted Turbine Torque, Backup TPA

Figure I-9.2.4-1



Predicted Turbine Flow, Backup TPA

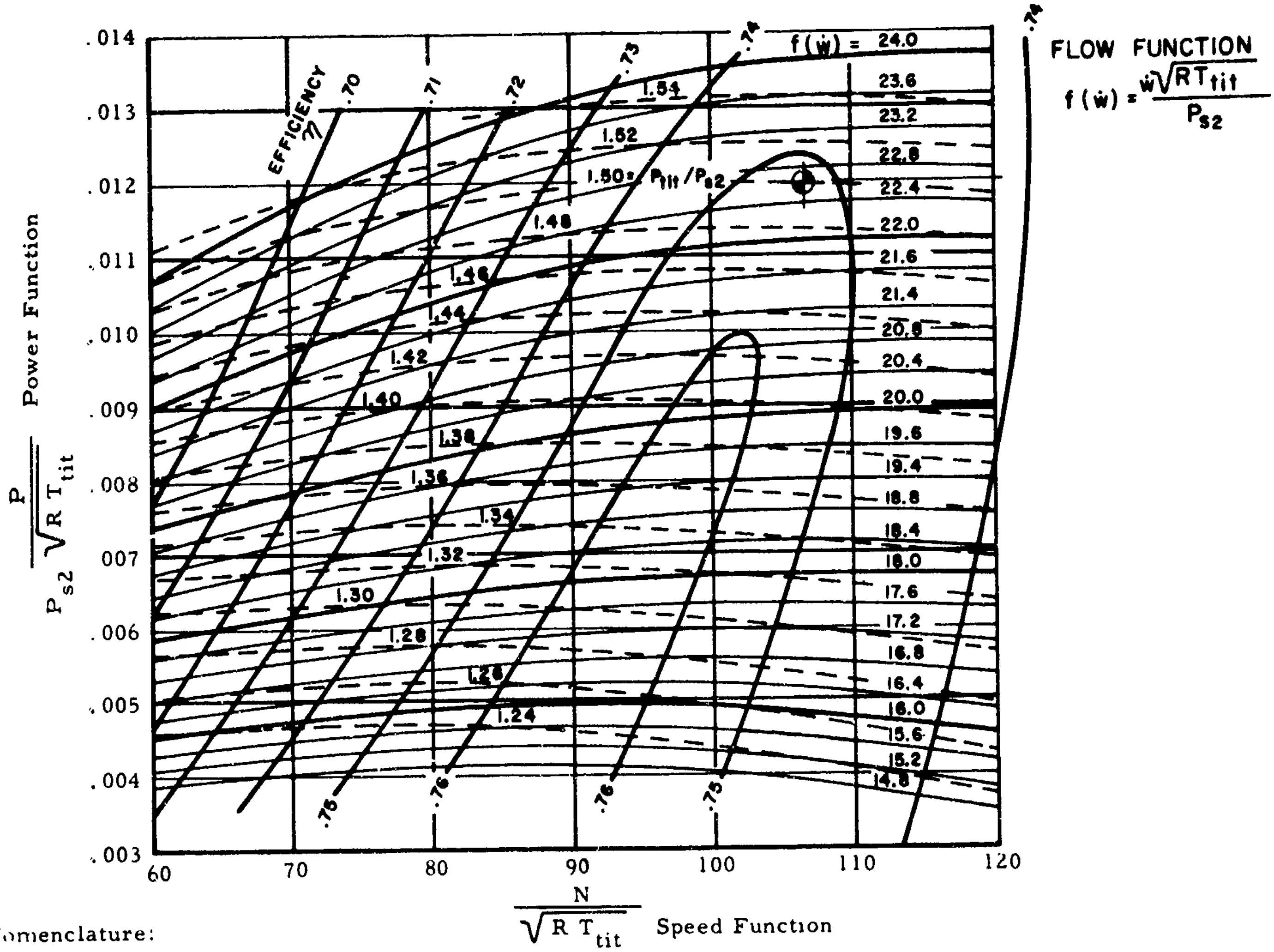


Nomenclature:

T_{ti} = Total turbine inlet temperature
P_{ti} = Total turbine inlet pressure
P_{s2} = Static turbine exhaust pressure
R = Gas constant
N = rpm
P = Horsepower

Predicted Turbine Power, Backup TPA

Figure I-9.2.4-3



Nomenclature:

T_{tit}	=	Total inlet temp.	°R				
P_{tit}	=	Total inlet pressure	psia	N	=	Speed	rpm
P_{s2}	=	Static exhaust pressure	psia	R	=	Gas Constant	ft/°R
P	=	Power output	hp	$\dot{w}$	=	Gas flow	lb/sec

$\gamma = C_p/C_v = 1.257$

Predicted Turbine Performance Map, Backup TPA

24 February 1966

Figure I-9.2.4-4

10.0 PROPELLANTS

10.1 FUEL

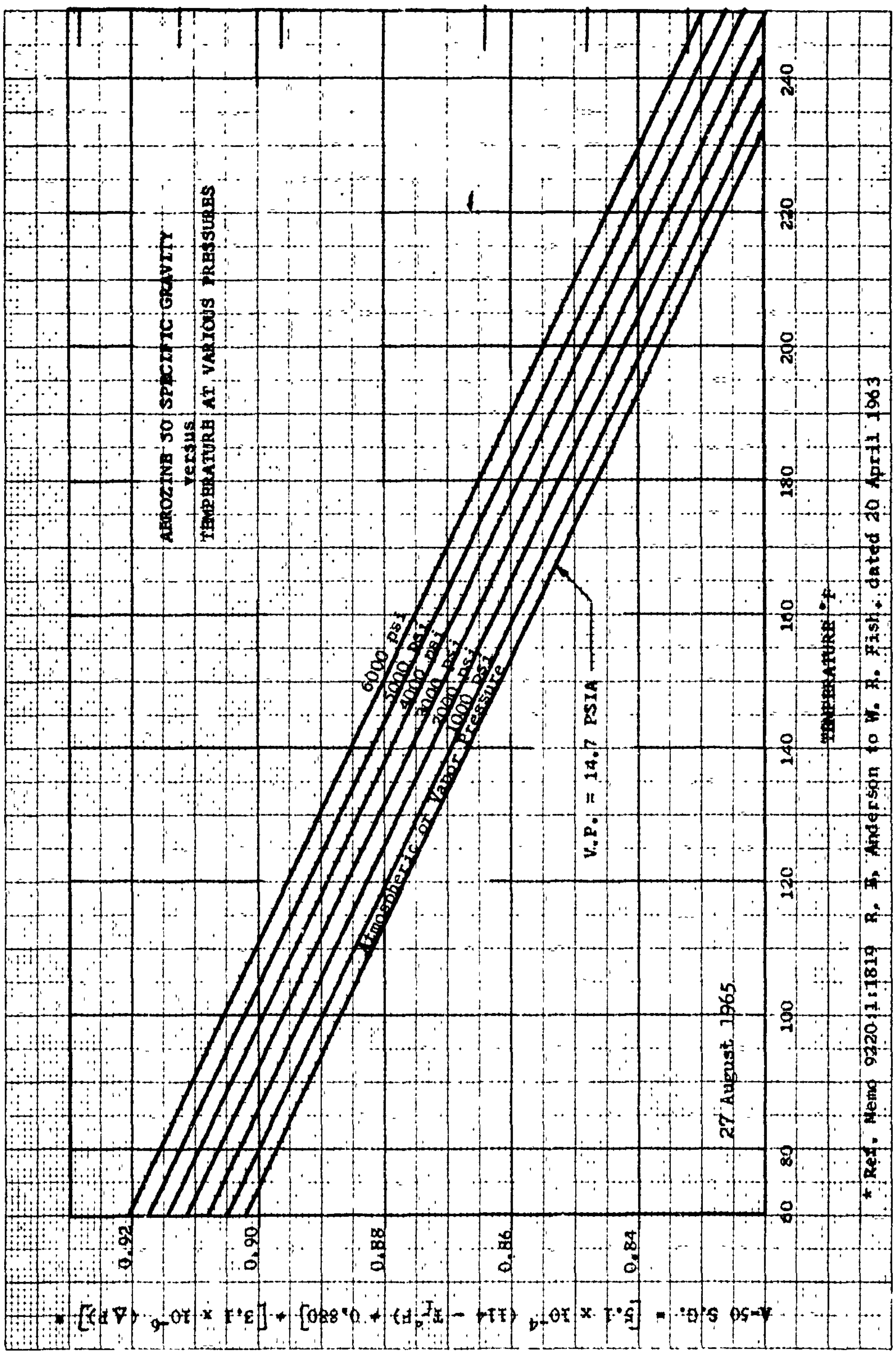
The fuel is AeroZINE 50 (50% N_2H_4 and 50% UDMH by weight). The properties of this fuel are shown in Figures 10.1-1 and 10.1-2.

10.2 OXIDIZER

The oxidizer is N_2O_4 (nitrogen tetroxide). The properties of this oxidizer are shown in Figures 10.2-1 through 10.2-5.

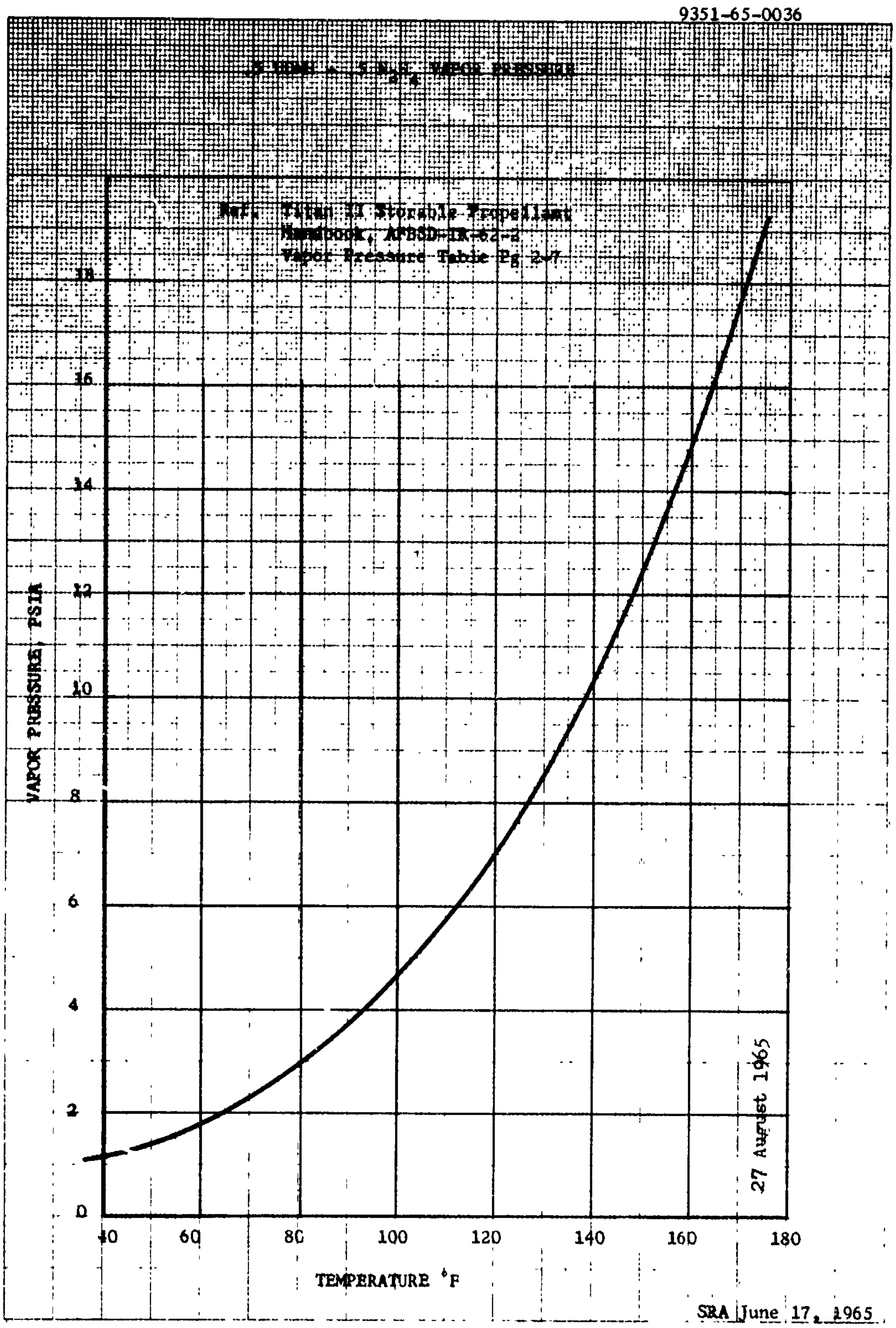
10.3 COMBUSTION GAS PROPERTIES

The properties of combustion gases of various oxidizer to fuel ratios are shown in Figures 10.3-1 through 10.3-5.



AeroZINE 50 Specific Gravity vs Temperature at Various Pressures

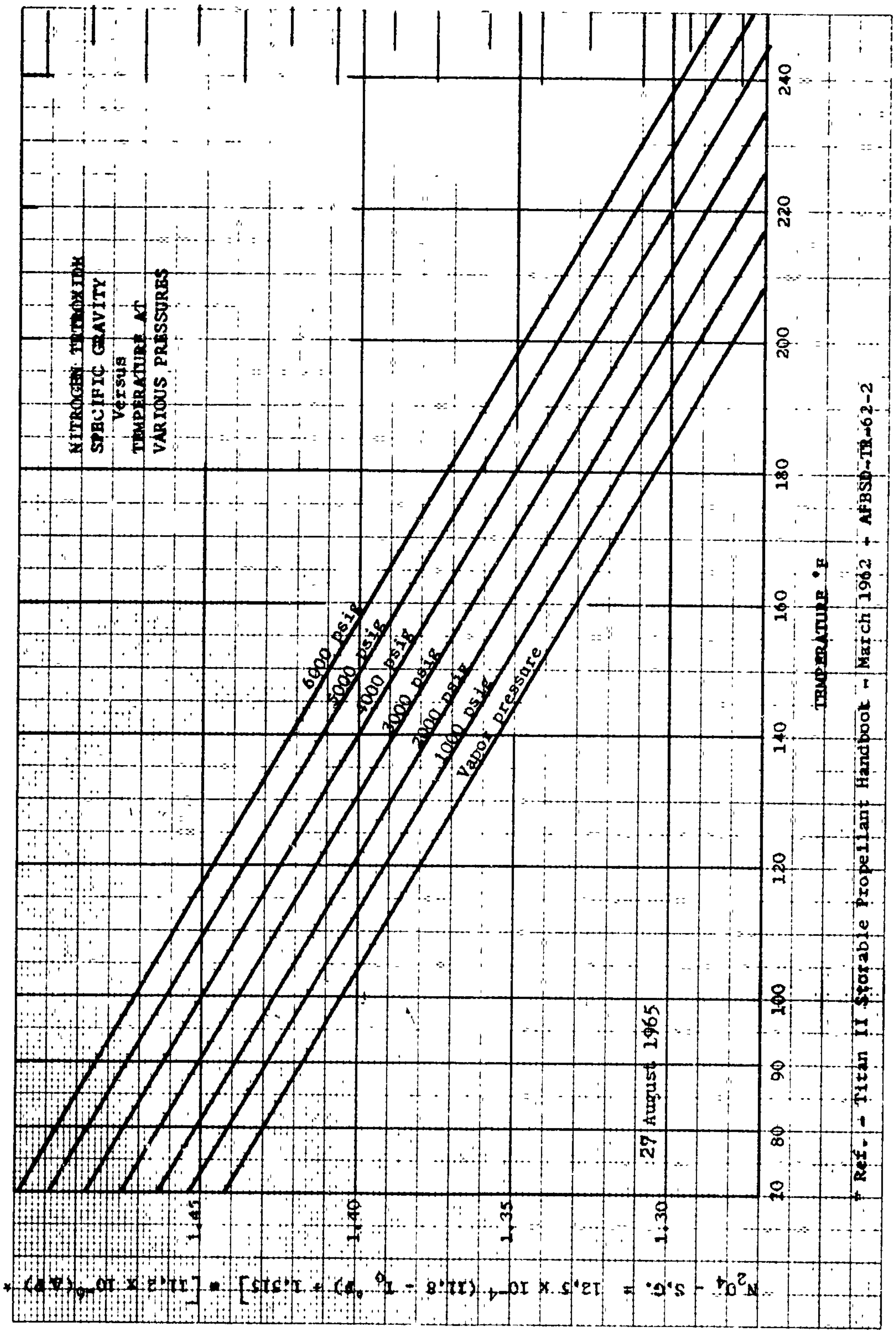
Figure I-10.1-1



.5 UDMH - .5 N_2H_4 Vapor Pressure

Figure I-10.1-2

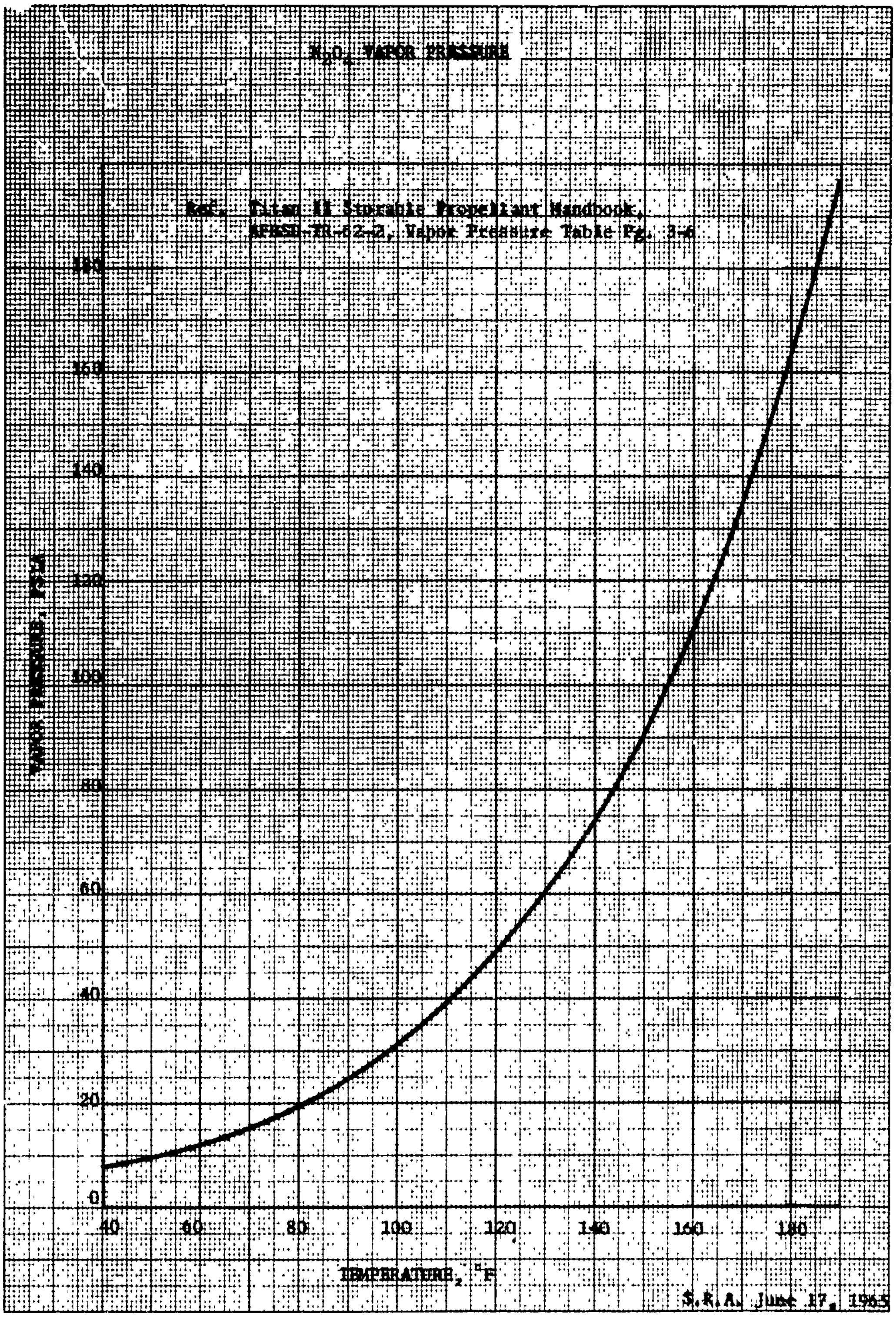
9351-65-0016



Nitrogen Tetroxide Specific Gravity vs Temperature at Various Pressures

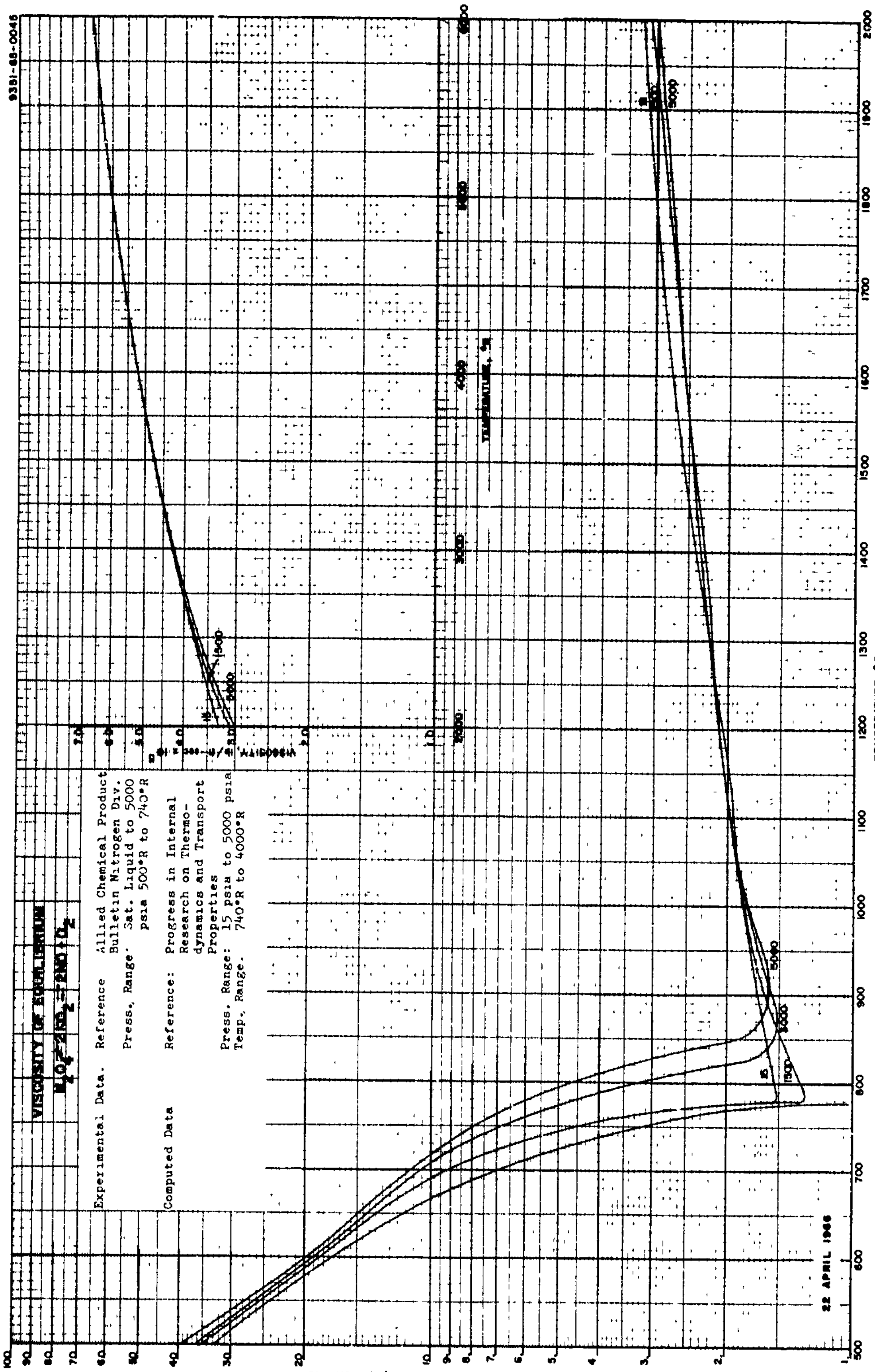
Figure I-10.2-1

9351-65-0035



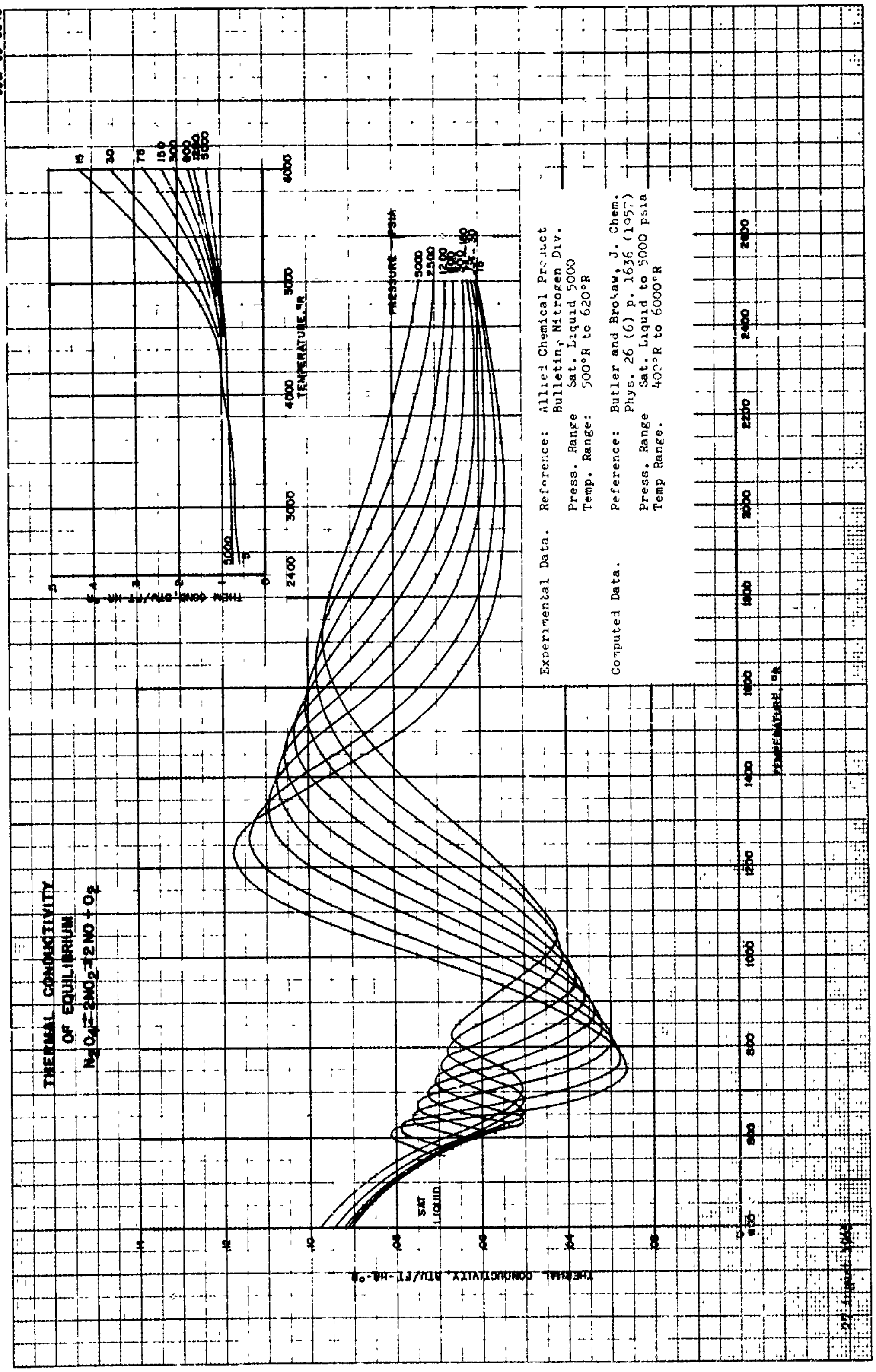
N_2O_4 Vapor Pressure

Figure I-10.2-2



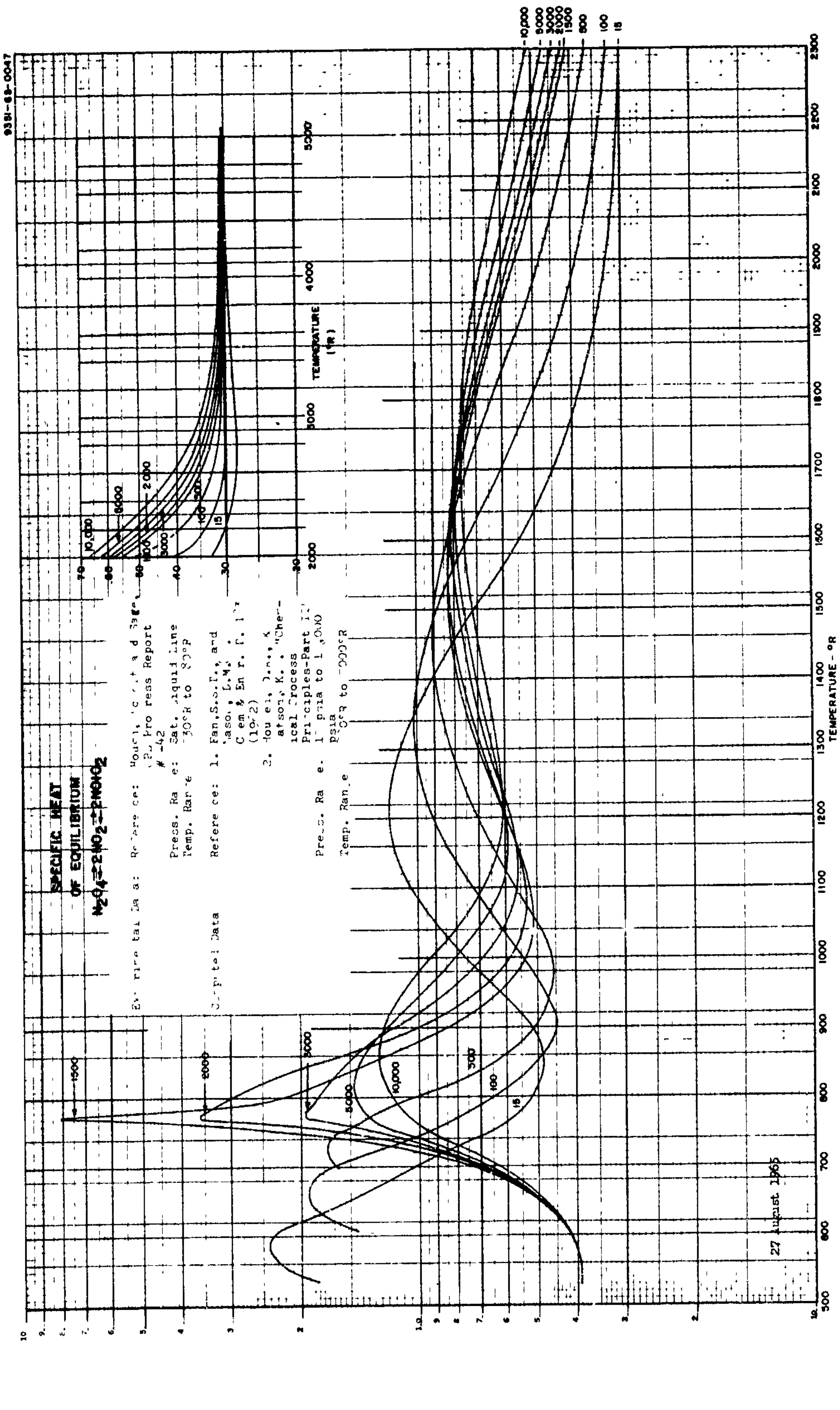
Viscosity of Equilibrium, N_2O_4

Figure I-10.2-3



Thermal Conductivity of Equilibrium N_2O_4

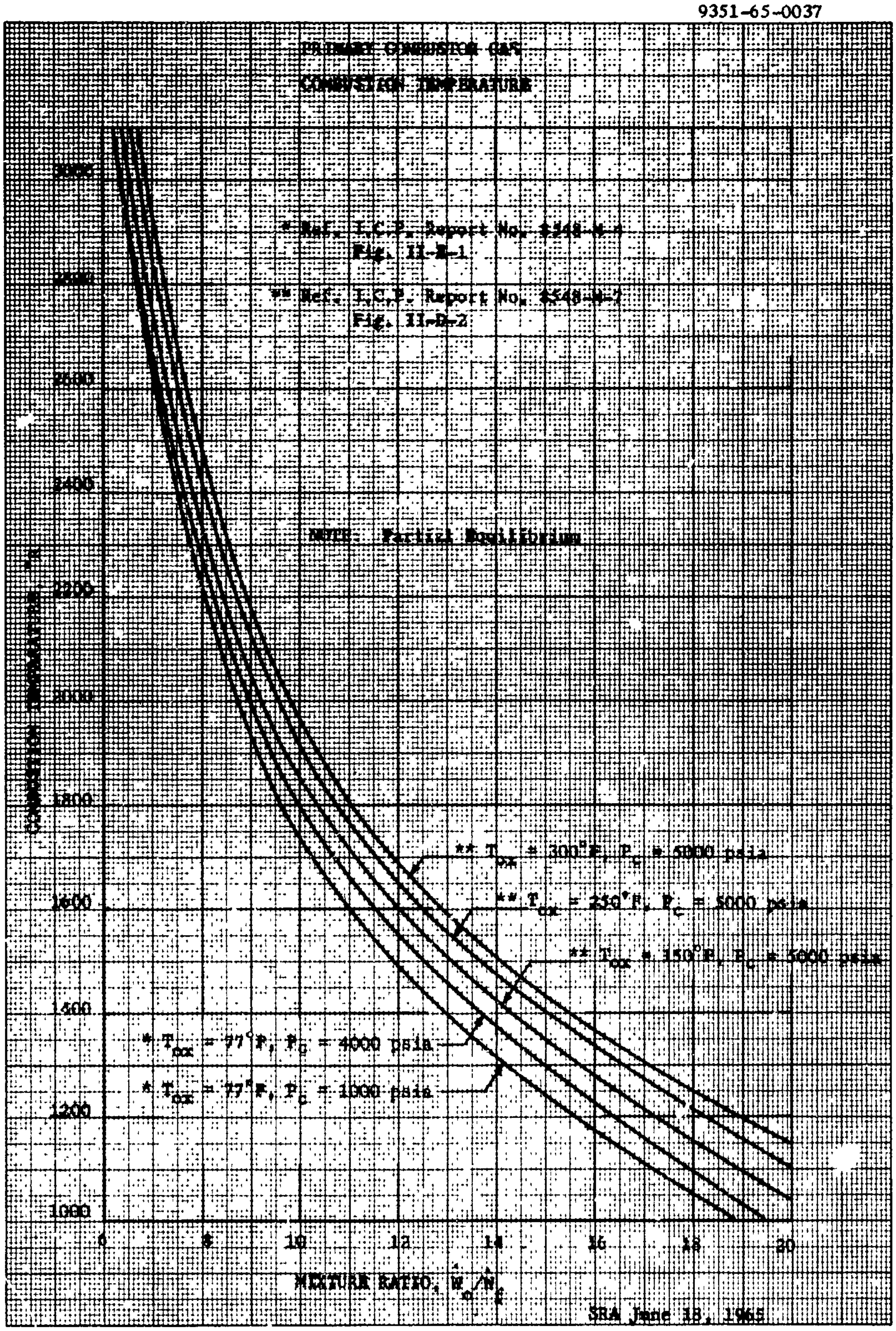
Figure I-10.2-4



Specific Heat of Equilibrium N_2O_4

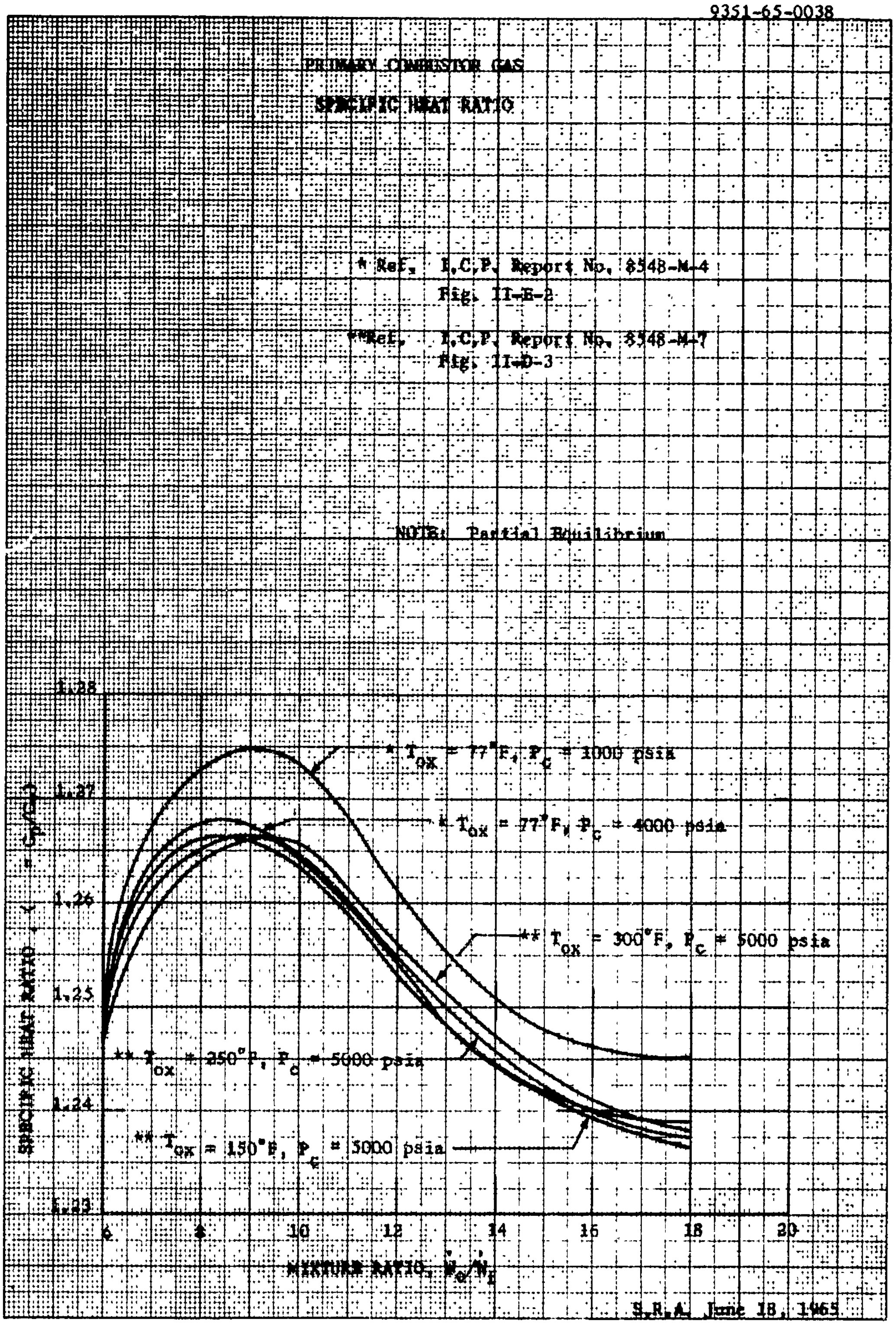
Figure I-10.2-5

9351-65-0037



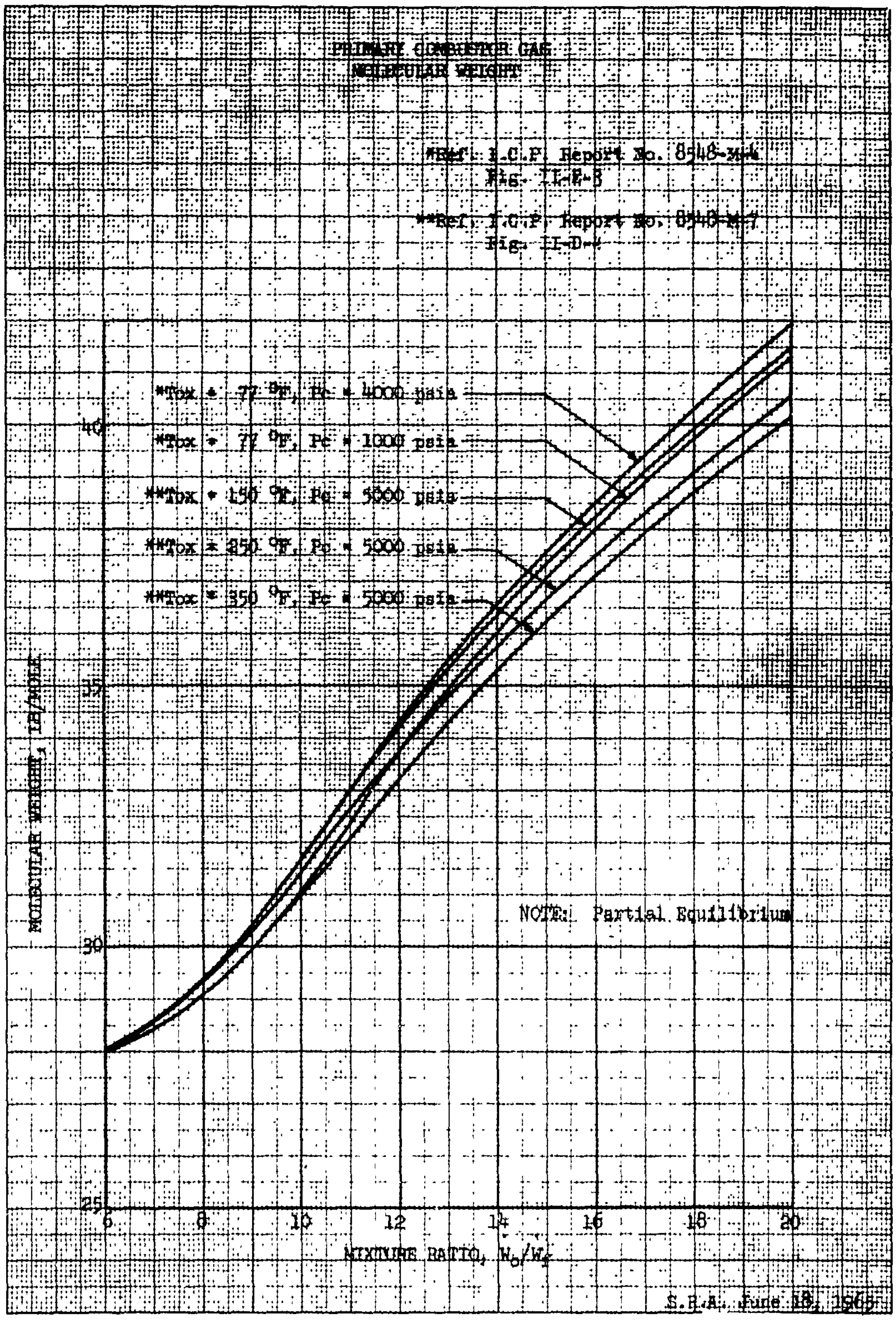
Primary Combustor Gas Combustion Temperature

Figure I-10.3-1



Primary Combustor Gas Specific Heat Ratio

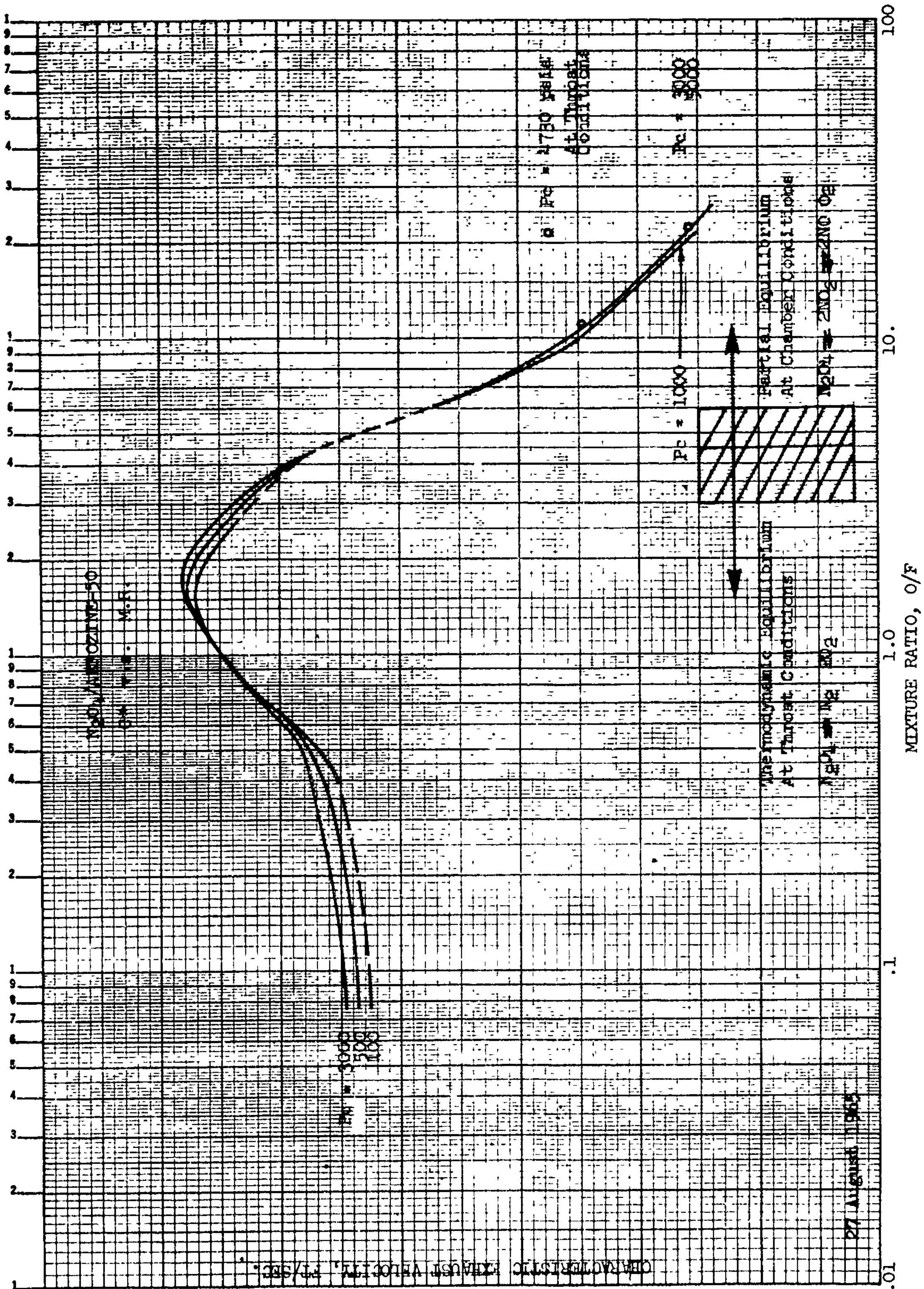
Figure I-10.3-2



Primary Combustor Gas Molecular Weight

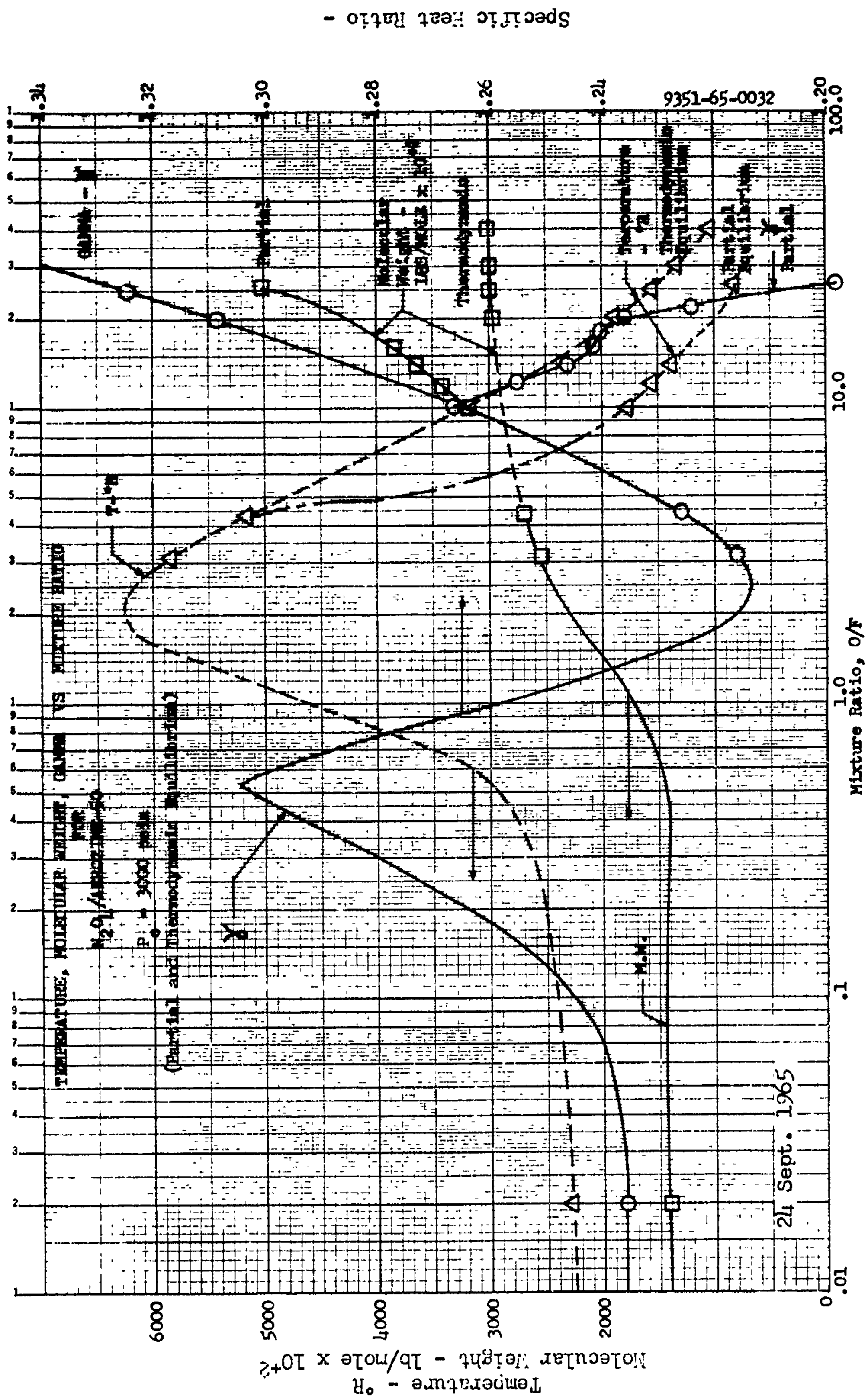
Figure I-10.3-3

9351-65-0034



N_2O_4/AeroZINE 50, C* vs M.R.

Figure I-10.3-4



Temperature, Molecular Weight, Gamma vs Mixture Ratio for N_2O_4/AeroZINE 50

Figure I-10.3-5

11.0 WEIGHT SUMMARY

11.1 Weight List - Advanced Turbopump Configuration

The engine module assembly weight list is shown in Table I-11.1-1 for the advanced turbopump configuration. This list gives the allocated and estimated or actual weight of components. When the actual weight of a component becomes available, it will supersede the estimated weight. Adjustments of allocated weights will be made as the component designs are firmed up.

TABLE I-11.1-1

ENGINE MODULE ASSEMBLY WEIGHT ALLOCATION
(ADVANCED TURBOPUMP CONFIGURATION)

	Allocated Weight, lb			Current Estimated or Actual Weight, lb
	Maximum	Target	Minimum	
Turbopump Housing, Oxidizer	234	189	123	196
Pump Housing, Fuel	90	60	50	58
Primary Injector and Liner	40	30	23	25
Rotor, Shaft, Impeller, and Inducers	28	19	18	24
Inducer Housings	22	19	16	13
Bearings	3	3	2	4
Combustion Seal and Flange	2	1	1	7
Turbine Nozzle	6	3	3	10
Turbine Exhaust Duct	4	3	2	3
Misc. Nuts, Labyrinths, Wear Rings, & Brg. Hsg.	10	7	6	7
Subtotals, Turbopump Assembly	439	334	244	347
Oxidizer Suction Valve	26	21	18	16
Fuel Suction Valve	26	21	18	14
Secondary Fuel Valve	5	4	3	4
Primary Fuel Valve	3	2	1	2
Secondary Fuel Valve Actuator	NA*	NA*	NA*	NA*
Primary Fuel Valve Actuator	NA*	NA*	NA*	NA*
Suction Valve Actuator (2)	NA*	NA*	NA*	NA*
Secondary Chamber	142	126	114	176
Secondary Injector	76	73	70	84
Miscellaneous bolts, gaskets, etc, TCA	20	15	10	15
Miscellaneous bolts, etc, other than TCA	13	7	6	7
Module Subassembly Total Dry Weight	750	603	484	665

* Not applicable. These items excluded from weight summary per Work Statement, Exhibit C, Paragraph III,B,2,b and Rf. Drwg 1120394.

TABLE I-11.1-1 (cont.)

ENGINE MODULE ASSEMBLY WEIGHT ALLOCATION

	Allocated Weight, lb			Current Estimated or Actual Weight, lb
	Maximum	Target	Minimum	
Module Subassembly Total Dry Weight	750	603	484	665
Fuel Suction Line Subassembly	NA*	NA*	NA*	NA*
Fuel Turbine Drive Line Subassembly	NA*	NA*	NA*	NA*
Oxidizer Suction Line Subassembly	NA*	NA*	NA*	NA*
Oxidizer Turbine Drive Line Subassembly	NA*	NA*	NA*	NA*
Fuel Boost Pump Subassembly	45	32	25	35
Oxidizer Boost Pump Subassembly	45	32	25	35
Instrumentation	NA*	NA*	NA*	NA*
Harnesses and Connectors	NA*	NA*	NA*	NA*
Miscellaneous bolts, gaskets, etc.	10	8	6	8
Engine Module Assembly Total	850	675	540	743

* Not applicable. These items excluded from weight summary per Work Statement, Exhibit C, Paragraph III,B,2,b and Ref Drwg 1120394.

12.0 MATERIALS SUMMARY

12.1 Materials List - Advanced Turbopump Configuration

The materials list for components of the engine module assembly, advanced turbopump configuration, is shown in Table I-12.1-1.

Table I-12.1-1

MATERIALS LIST
ENGINE MODULE ASSEMBLY
(ADVANCED TURBOPUMP CONFIGURATION)

Part	Material Surface Temp°F & Medium			Material
	Fuel	Oxid	Gas	
1. Oxid Housing	200°F	300°F	600°F	INCO 718C
2. Fuel Housing	77°	-	-	17-4 PH Cast
3. Shaft and Turbine Rotor	200°	300°	1400°	Waspalloy
4. Turbine Shaft Labyrinth Insert	200° (soak back)	-	-	Graphite Filled Vespel SP-21
5. Nozzle Turbine	-	-	1400°	Udimet 700 Cast
6. Hydrostatic Fuel Seal	200°	300°	1200°	Invar, LC-1 Flame Plating on Surface, Bellows-Inco 718
7. Wear Ring Turbine	-	-	1400°	Haynes Alloy No. 25, Type A60 Fibers, 25% Density
8. Turbine Exhaust Duct	-	-	1200°	Hastalloy X
9. Fuel Pump, 1st Stage Impeller	77°	-	-	LC-1 Flame Plate on Surface SS 17-4PH Cast
10. Fuel Pump, 1st Stage Labyrinth Insert	77°	-	-	Pressure Relieved Kynar
11. Fuel Pump Inducer	77°	-	-	Titanium 6A1-4V
12. Fuel Pump Impeller Nut	77°	-	-	AM 355
13. Fuel Pump Inducer Hsg	77°	-	-	SS 347, LC-1 Flame Plate on Surface
14. Fuel Pump 2nd Stage impeller	77°	-	-	AM 355
15. Fuel Pump 2nd Stage Labyrinth Insert	77°	-	-	Reinforced Kynar
16. Fuel Pump 2nd Stage Back Vane Plate	77°	-	-	AM 355

TABLE I-12.1-1 (cont.)

Materials List (Cont.)

Part	Material Surface Temp°F & Medium			Material
	Fuel	Oxid	Gas	
17. Fuel Pump Radial Bearing Housing	77°	-	-	SS 347, LC-1 Flame Plate on Surface
18. Fuel Pump Radial Bearing Housing Retaining Nut	77°	-	-	AM 355
19. Fuel Pump Radial Bearing	200°	-	-	SS 440C Rollers & Races, Glass Filled Teflon Cages
20. Fuel Pump Radial Bearing Retaining Nut	77°	-	-	SS 347
21. Fuel Pump Thrust Bearing Sleeve	77°	-	-	AM 350
22. Fuel Pump Thrust Bearings	200°	-	-	SS 440C Races, K5H Balls, Glass Filled Teflon Cages
23. Fuel Bearing Shaft Retaining Nut	77°	-	-	AM 355
24. Oxid Pump Impeller	-	77°	-	17-4 PH Cast LC-2 Flame Plate on Surface
25. Oxid Pump Impeller Hydrostatic Seal	-	77°	-	LC-1 Flame Plate on Surface
26. Oxidizer Pump Inducer	-	77°	-	AM 355
27. Oxid Pump Impeller Nut	-	77°	-	AM 355
28. Oxid Pump Inducer Housing	-	77°	-	Cres 347
29. Oxid Pump Radial Bearing	-	200°	-	SS 440C Rollers & Races, Glass Filled Teflon Cages
30. Oxid Pump Radial Bearing Retaining Nut	-	77°	-	AM 350
31. Oxid Pump Labyrinth Insert	-	77°	-	Graphite Filled Vespel SP-21
32. Boost Pump Suction Housing	77°	77°	-	Inco 718

TABLE I-12.1-1 (cont.)
Materials List (Cont.)

Part	Material Surface Temp°F & Medium			Material
	Fuel	Oxid	Gas	
33. Boost Pump Discharge Housing	77°	77°	-	AL A356 Cast
34. Boost Pump Impellers	77°	77°	-	AL 7075-T73
35. Boost Pump Impeller Nuts	77°	77°	-	AL 7075-T6
36. Boost Pump Shafts	77°	77°	-	AM 355
37. Boost Pump Bearing Housing	77°	77°	-	AM 355
38. Boost Pump Bearings	200°	200°	-	SS 440C Rolling Elements & Races, Glass Filled Teflon Cages.
39. Boost Pump Bearing Retaining Nuts	77°	77°	-	SS 347
40. Boost Pump Turbine Rotor	77°	77°	-	AM 355
41. Boost Pump Turbine Stators	77°	77°	-	AM 355

TABLE I-12.1-1 (cont.)

Materials List (cont.)

Part	Material Surface Temp°F & Medium: Fuel	Oxid	PC Gas	SC Gas	Materials	Alternates
42. Fuel Suction Valve	77°					
Body					SS-ACl-Type CF3	AL-A 356
Inlet					SS304L	
Eyelid					SS304L	
Diaphragm					SS304L	
Cam					SS-440A	
Shaft					SS-17-4PH	AM 350
Bearings					SS-440C	
Springs					SS-17-7PH	
Seals					Teflon	
Torque Bar					SS304	
43. Primary Fuel Valve	100°					
100°						
Shaft					AM-350	17-4 PH
Sleeve					17-4PH	AM-350
Bearings					440C	
Dyn. Seals					Teflon	
Static Seals (Low Pressure Only)					AS 4004(Butyl)	
44. Secondary Fuel Valve	90°				Same as Primary Fuel Valve	
45. Oxid Suction Valve	-	77	-	-	Same as Fuel Suct. Va.	
46. Fuel Suction Line	77	-	-	-	Braid, S.S. Lining, Teflon(Preliminary)	
47. Oxid Suction Line	-	77	-	-	Braid, S.S. Lining, Teflon(Preliminary)	
48. Boost Pump Turbine Feed Line Fuel or Oxid	90°	90°			Mil-T-6845 304	
49. Check Valve-Feed Line						
Fuel or Oxid	90°	90°				
Body					17-4 PH	
Springs					17-7 PH	
Poppet					SS 316	
Seat					Kynar	Teflon

TABLE I-12.1-1 (cont.)

Materials List (cont.)

Part	Material Surface Temp°F & Medium				Materials	Alternates
	Fuel	Oxid	PC Gas	SC Gas		
50. Primary Injector (and turbine housing)	200°F	300°F	1225	-	INCO 718	Hast X
51. Primary Combustor Liner	-	-	1225 1500	-	Hast X	Rene' 62 INCO 718
52. Secondary Injector			1225		SS 347	INCO 718
53. Secondary Combustor Regen Tubes	-	900 (Inner) 1500 (Outer)	- -	- -	INCO 718	
Oxid. Resistant Coating	-	3300	-	-	Classified	
Transpiration	-	2000 (Local) 1500 (Avg.)	-	-	SS 347	

13.0 CONFIGURATION SUMMARY (BPL)

13.1 MODULE

Module interface drawings are listed in Table I-13.1-1.

13.2 TURBOPUMP, ADVANCED CONFIGURATION

The basic parts lists (BPL) for the advanced turbopump assembly, the oxidizer boost pump assembly, and the fuel boost pump assembly are in Tables I-13.2-1, I-13.2-2, and I-13.2-3, respectively.

TABLE I-13.1-1

MODULE INTERFACE SUMMARY

	Interface	Drawing Number
1.	Oxid Hsg Thrust Takeout	1129274
2.	Oxid Hsg to Oxid. Suction Valve	1129090
3.	Oxid Suction Valve to Oxid Suction Line	1129541
4.	Oxid Suction Line to Oxid Boost Pump	1130437
5.	Oxid Hsg to Oxid Check Valve	1129140
6.	Oxid Check Valve to Oxid Turb. Hyd. Line	1129140
7.	Oxid Turb Hyd Line Orifice to Oxid Boost Pump	1129142
8.	Oxid Boost Pump Suction Interface	1130335
9.	Oxid Hsg Handling Lug - Upper	1129274
10.	Oxid Hsg Handling Lug - Lower	1129274
11.	Fuel Hsg to Fuel Suction Valve	1129091
12.	Fuel Suction Valve to Fuel Suction Line	1129541
13.	Fuel Suction Line to Fuel Boost Pump	1130437
14.	Fuel Hsg to Fuel Check Valve	1129141
15.	Fuel Check Valve to Fuel Turb Hyd Line	1129141
16.	Fuel Turb Hyd Line Orifice to Fuel Boost Pump	1129143
17.	Fuel Boost Pump Suction	1130335
18.	Fuel Pump Housing to Primary Control Fuel Valve	1129666
19.	Fuel Pump Outlet to Fuel Coupling	1129409
20.	Secondary Injector to Secondary Fuel Valve	1132066
21.	Turbopump Oxid. Hsg to Secondary Injector	1128954
22.	Secondary Combustion Chamber to Secondary Injector	1128956
23.	Actuator PCFV to PCFV	1130819
24.	Actuator SCFV to SCFV	1130774
25.	Primary Inj to Oxid Hsg	1130780
26.	Primary Inj to Fuel Hsg	1130781
27.	Secondary Inj Fuel Inlet to Fuel Coupling	1129490
28.	Fuel Turb Hyd Line Orifice to Fuel Turb Hyd Line	1129143
29.	Oxid Turb Hyd Line Orifice to Oxid Turb Hyd Line	1129142
30.	Primary Combustor Liner to Turbine Stator	1131003
31.	Turbine Stator to P.C. Injector	1130826

BASIC PARTS LIST

DRAWING NO.	
SHEET 1	OF 3

LTR.	DATE	REVISION	BY	CK.D
W/C	3/10/67	Original		

TITLE: TPA, T-ENGINE, ARES

AEROJET-GENERAL CORPORATION

DRAWN	DATE [illegible]-24-67
CHECKED	
APPROVED	

SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D		
	-9		X						TPA (ARES)	1		
	1130139-9			X					SHAFT	1		
	1130139-1				X				SHAFT (MACH.)	1		
	1130886-3					X			FORGING, SHAFT	1		
	1130886-1						X		FORGING, SHAFT	1		
	1130139-3				X				PLATE	1		
	1130139-5				X				ROD	6		
					X				WELD ROD	AR		
	1129936-19			X					STATOR ASSY, TURBINE	1		
	1129936-1				X				STATOR (MACH)	1		
	1129823-1					X			STATOR, TURBINE - CAST	1		
	1129936-9				X				SUB ASSY	1		
	1129936-3					X			RING	1		
	1129936-5					X			WEAR RING	1		
	1129936-7				X				WEAR RING	1		
	1129822-1			X					IMPELLER, FUEL	1		
	1129888-1				X				IMPELLER, FUEL - CASTING	1		
	1130149								COORDINATES			
	1130022-1			X					IMPELLER, OXIDIZER	1		
	1130085-1				X				IMPELLER, OXIDIZER - CASTING	1		
	1129825								COORDINATES			
	1129986-9			X					INDUCER, FUEL	1		
	1129986-1				X				INDUCER (MACH)	1		
	1129819-3					X			FORGING, INDUCER - FUEL (MACH)	1		

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Basic Parts List (Planned)

Turbopump Assembly

Table I-13.2-1 Sheet 1 of 3

BASIC PARTS LIST

DRAWING NO.	
SHEET 2	OF 3

LET.	DATE	REVISION	BY	CKD
N/C	3/10/67	Original		

TITLE

AEROJET GENERAL CORPORATION

DRAWN	DATE 1-24-67
CHECKED	
APPROVED	

SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D.		
	1129819-1						X		FORGING, INDUCER - FUEL	1		
	MS 16556-625				X				PIN	3		
	1129937								COORDINATES			
	1130237-1			X					INDUCER, OXIDIZER	1		
	1129854-3				X				FORGING, INDUCER - OXIDIZER (MACH)	1		
	1129854-1					X			FORGING, INDUCER - OXIDIZER	1		
	1130887								COORDINATES			
	1130559-1			X					IMPELLER - FUEL, 2ND STAGE	1		
	1130828-1			X					NUT, IMPELLER - OXIDIZER	1		
	1130930-1			X					NUT, RETAINING - THRUST BEARING	1		
	1130434-1			X					RING - RETAINER, TURBINE STATOR	1		
	1130932-9			X					NUT, RETAINING - ROLLER BRG. HSG.	1		
	1130932-1				X				4.75 DIA BAR	1		
	COML. PRODUCT				X				LONG-LOK INSERT	1		
	1130779-9			X					BACKPLATE, PUMP - 2ND STAGE	1		
	1130779-1				X				4.25 DIA BAR	1		
	COML. PRODUCT				X				LONG-LOK INSERT	1		
	1130624-1			X					HOUSING, BEARING - FUEL	1		
	1130931-9			X					NUT, RETAINING - ROLLER BEARING	1		
	1130931-1				X				3.50 DIA BAR	1		
	COML. PRODUCT				X				LONG-LOK INSERT	1		
	1130868-1			X					LOCK WASHER, OXIDIZER	1		
	1130629-1			X					RING, LOCK - ROLLER BEARING	1		
	1130764-1			X					LOCK WASHER, FUEL	1		

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Basic Parts List (Planned)
Turbopump Assembly

BASIC PARTS LIST

DRAWING NO.

SHEET 3 OF 3

LET.	DATE	REVISION	BY	CKD
W/C	3/10/67	Original		

TITLE

AEROJET GENERAL CORPORATION

DRAWN: L. Pinell — DATE: 1-24-67

CHECKED

APPROVED

SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D		
	1130827-1			X					NUT, IMPELLER - FUEL PUMP	1		
	1123434-9			X					HOUSING, BEARING	1		
	1123434-1				X				4.25 DIA BAR	1		
	1123434-3				X				3.00 DIA BAR	1		
	1122027-1			X					NUT, BEARING	1		
	1123715			X					BRG, SET, BALL THRUST - DUPLEX - DB	1		
	1131959-9			X					ROLLER BEARING, CYLINDRICAL - SELF ALIGNING	2		
	1131959-1				X				ROLLER BEARING	1		
	1130431-9				X				ROLLER BEARING CAGE	1		
	1130431-1					X			2.50 DIA BAR	1		
	1130431-3					X			2.50 DIA BAR	1		
	1130431-5					X			.031 DIA ROD	13		

AGC 2-327 CC 87540-00661

Basic Parts List (Planned)

Turbopump Assembly

Table I-13.2-1 Sheet 3 of 3

BASIC PARTS LIST

DRAWING NO.
SHEET 1 OF

LTR.	DATE	REVISION	BY	CKD
N/C	3/10/67	Original		

TITLE: OXIDIZER BOOST PUMP - ARES

AEROJET GENERAL CORPORATION

DRAWN: [illegible] DATE 1/24/67
CHECKED
APPROVED

SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D.		
	-9		X						BOOST PUMP ASSY.			
	1122678-5			X					HOUSING DISCHARGE - BOOST PUMP	1		
	1122678-1				X				HOUSING, DISCHARGE - BOOST PUMP	1		
	1122257-1					X			HOUSING, DISCHARGE - CASTING, BOOST PUMP	1		
	NAS1394C3L				X				INSERT	8		
	1130625-9			X					HOUSING, INLET - BOOST PUMP	1		
	1130625-1				X				HOUSING, INLET - BOOST PUMP	1		
	1130626-3					X			FORGING, TURBINE HSG - BOOST PUMP	1		
	1130626-1						X		FORGING, ROUGH	1		
	1130625-3				X				1.375 O.D. X .120 WALL TUBING	1		
	1130625-5				X				2.375 DIA BAR	1		
	AGC 44198				X				WELD ROD	AR		
	1130995-9			X					ROTOR TURBINE - BOOST PUMP	1		
	1130995-1				X				1.00 PLATE	1		
	1130995-3				X				1.00 PLATE	1		
	COML. PRODUCT				X				BRAZE ALLOY	AR		
	1130640-9			X					SHAFT - BOOST PUMP	1		
	1130640-1				X				1.62 DIA BAR	1		
	MS 16556-634				X				PIN, DOWEL	3		
	1130636-9			X					INDUCER, OXIDIZER - BOOST PUMP	1		
	1130636-1				X				INDUCER, OXIDIZER BOOST PUMP	1		
	1130776-3					X			FORGING, INDUCER - BOOST PUMP	1		
	1130776-1						X		FORGING, ROUGH	1		
	MS 16556-634				X				PIN, DOWEL	3		

AGC 2-327 CC 87540-00661

Basic Parts List (Planned)

Oxidizer Boost Pump

10 March 1967 Table I-13.2-2, Sheet 1 of 2

BASIC PARTS LIST

DRAWING NO.
SHEET 2 OF 2

LET.	DATE	REVISION	BY	CK.D
W/C	3/10/67	Original		

TITLE

AEROJET GENERAL CORPORATION

DRAWN K. Burrell 1/4/67
CHECKED
APPROVED

SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D.		
	1129824								COORDINATES			
	1130630-1			X					HOUSING, BRG. - BOOST PUMP	1		
	1130775-1			X					STATOR, TURBINE - OXIDIZER BOOST PUMP	1		
	1130879-1			X					LOCK NUT, BRG. - BOOST PUMP	1		
	1130672-1			X					RING, LOCK - BOOST PUMP	1		
	1130881-9			X					LOCK NUT, BRG. - BOOST PUMP	1		
	1130881-1				X				2.25 DIA BAR	1		
	COML. PRODUCT				X				LONG-LOK INSERT	1		
	1130869-1			X					LOCK WASHER, OXIDIZER - BOOST PUMP	1		
	1130878-1			X					NUT, OXIDIZER INDUCER - BOOST PUMP	1		
	1130632-1			X					SPACER, OUTER - BOOST PUMP	1		
	1130631-1			X					SPACER, INNER - BOOST PUMP	1		
	1130926-1			X					SHIM, INDUCER - BOOST PUMP	AR		
	1130926-3			X					SHIM, INDUCER - BOOST PUMP	AR		
	1130926-5			X					SHIM, INDUCER - BOOST PUMP	AR		
	1130926-7			X					SHIM, INDUCER - BOOST PUMP	AR		
	1129183								BOOST PUMP LAYOUT			

AGC 2-327 CC 87540-00661

Basic Parts List (Planned)

Oxidizer Boost Pump

Table I-13.2-2, Sheet 2 of 2

BASIC PARTS LIST

DRAWING NO.

SHEET 1 of 2

LET.	DATE	REVISION	BY	CKD
C	3/10/67	Original		

TITLE: FUEL BOOST PUMP - ARES

AEROJET-GENERAL CORPORATION

DRAWN: [illegible] DATE: 1/24/67

CHECKED

APPROVED

SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D.		
	-19		X						BOOST PUMP ASSY.			
	1122678-5			X					HOUSING, DISCHARGE - BOOST PUMP	1		
	1122678-1				X				HOUSING, DISCHARGE - BOOST PUMP	1		
	1122257-1					X			HOUSING, DISCHARGE - CASTING, BOOST PUMP	1		
	NAS1394C3L				X				INSERT	8		
	1130625-9			X					HOUSING, INLET - BOOST PUMP	1		
	1130625-1				X				HOUSING, INLET - BOOST PUMP	1		
	1130626-3					X			FORGING, TURBINE HSG - BOOST PUMP	1		
	1130626-1						X		FORGING, ROUGH	1		
	1130625-3				X				1.375 O.D. X .120 WALL TUBING	1		
	1130625-5				X				2.375 DIA BAR	1		
	AGC 44198				X				WELD ROD	AR		
	1130995-9			X					ROTOR TURBINE - BOOST PUMP	1		
	1130995-1				X				1.00 PLATE	1		
	1130995-3				X				1.00 PLATE	1		
	COML. PRODUCT				X				BRAZE ALLOY	AR		
	1130640-9			X					SHAFT - BOOST PUMP	1		
	1130640-1				X				1.62 DIA BAR	1		
	MS 16556-634				X				PIN, DOWEL	3		
	1130665-9			X					INDUCER, FUEL - BOOST PUMP	1		
	1130665-1				X				INDUCER, FUEL - BOOST PUMP	1		
	1130776-3					X			FORGING, INDUCER - BOOST PUMP	1		
	1130776-1						X		FORGING, ROUGH	1		
	MS 16556-634				X				PIN, DOWEL	3		

AGC 2-327 CC 87540-00661

Basic Parts List (Planned)

Fuel Boost Pump

Table I-13.2-3 Sheet 1 of 2

BASIC PARTS LIST

DRAWING NO.

SHEET 2 OF 2

LET.	DATE	REVISION	BY	CKD
N/C	3/10/67	Original		

TITLE

AEROJET GENERAL CORPORATION

DRAWN L. Powell DATE 1/24/67

CHECKED

APPROVED

SIZE	DWG. NO.	REV.	1	2	3	4	5	6	PART NAME	NO. REQ'D.		
	1130073								COORDINATES			
	1130630-1			X					HOUSING, BRG. - BOOST PUMP	1		
	1130775-3			X					STATOR, TURBINE - FUEL BOOST PUMP	1		
	1130879-1			X					LOCK NUT, BRG. - BOOST PUMP	1		
	1130672-1			X					RING, LOCK - BOOST PUMP	1		
	1130881-9			X					LOCK NUT, BRG. - BOOST PUMP	1		
	1130881-1				X				2.25 DIA BAR	1		
	COML. PRODUCT				X				LONG-LOK INSERT	1		
	1130870-1			X					LOCK WASHER, FUEL - BOOST PUMP	1		
	1130877-1			X					NUT, FUEL INDUCER - BOOST PUMP	1		
	1130632-1			X					SPACER, OUTER - BOOST PUMP	1		
	1130631-1			X					SPACER, INNER - BOOST PUMP	1		
	1130926-1			X					SHIM, INDUCER - BOOST PUMP	AR		
	1130926-3			X					SHIM, INDUCER - BOOST PUMP	AR		
	1130926-5			X					SHIM, INDUCER - BOOST PUMP	AR		
	1130926-7			X					SHIM, INDUCER - BOOST PUMP	AR		
	1129183								BOOST PUMP LAYOUT			

AGC 2-327 CC 87540-00661

Basic Parts List (Planned)

Fuel Boost Pump

Table I-13.2-3 Sheet 2 of 2

FIGURE LIST

FIGURE LIST (cont.)

I. INTRODUCTION

(U) It was realized early in the ARES suction valve concept-design stages that a storable seal and cutter development program was necessary to validate design criteria for the configuration and installation of the shear seal and cutter. Empirical data was needed to establish clearance gaps, tooth depth, and cutting angle of the cutter because both the shearing stroke and force were limited by the valve design.

(U) Tests results indicate that the design established closely approaches an optimum configuration for this particular application.

II. STORAGE SEAL AND CUTTER DEVELOPMENT

(U) Storage seal-development testing was conducted to achieve a structurally sound shear seal installation and a cutter configuration capable of shearing the 304L annealed 0.003-in.-thick foil seal cleanly without generating contaminates, while operating within torque and response requirements.

(U) Blanks for the development cutters were made from carpenter "VEGA" tool steel heat treated to RC 60. The first cutter fabricated had three chisel points and a tooth depth of 0.070 to 0.080 in. The shearing force was in excess of the allowable, indicating that more points were required to increase the shearing angle and reduce the shearing force. The allowable force was established by the strength of the actuating cam at a maximum value of 1800 lb with a design goal of 1000 lb. The 1800 lb force corresponds to a valve actuation torque of approximately 200 in. lb.

(U) The second cutter configuration, Figure II-1 Views A and B, had nine chisel points with a tooth depth "A" of 0.065 to 0.075 in., and a cutter angle, of "B" 3° 30' and point angle "C" at 3° 30'. The cutter and foil seal were installed in a test fixture simulating their installation into a suction valve, Figure II-1 View C. Point gap "F," was 0.003 to 0.005 in., radial

clearance "C" was 0.006 to 0.010 in. This configuration reduced the shearing force well within the allowable, however the foil seal was tearing at each tooth point. Examination and analysis indicated a local tensile failure of the foil before being sheared by the root of each tooth. This tearing condition was lessened by reducing the tooth depth and simultaneously increasing the point angle "C" to 15°. Tearing was further lessened when the point angle was increased to 30° and entirely eliminated when the point angle was increased to 60° with the depth "A" reduced to 0.045 to 0.050 in. A 10° rake angle "D" was added to eliminate the chisel points, thus providing a sharper cutting edge which improved both the piercing and shearing action. The shallower tooth depth increased the shearing force because of the reduced cutter angle "B", however, a final configuration having 10 points increased the cutter angle sufficiently to bring the shearing force very near the design goal of 1000 lb.

(U) Several seal cutters and test specimens of various designs were fabricated for the electron beam-welding program during the development of the cutter.

(U) Tests conducted with the electron beam-welded shear seal and cutter assemblies resulted in establishing the radial clearance, gap "G" (Figure II-1 View C) at 0.005 to 0.008 in. (the gap should be greater than the foil thickness to prevent jamming) and the cutter axial clearance from the surface of the foil seal, point gap "F", at 0.002 to 0.005 in. Point gap is necessary to protect the seal from being prematurely cut due to cutter movement caused by variations of fluid head pressure acting upon the valve gate.

(U) Both nine and ten point configuration cutters were fabricated and tested in the prototype valves. Each cutter demonstrated its capability of shearing the 304L annealed 0.003-in.-thick electron-beam welded in seal cleanly and within design torque and response requirements.

II, Storage Seal and Cutter Development (cont.)

(U) Results of the tests indicate that the established design closely approaches an optimum configuration for this particular application. The most critical variables were determined to be (1) the number of teeth which established the initial piercing force, (2) the cutter shearing angle of each tooth which affects the shearing force, (3) the depth of tooth and gap clearance which coupled with the sharpness of the cutter edge affects the cleanliness of the shear.

(U) The piercing and shearing forces of the established cutters were consistently within design limits; however, the cleanliness of the shear cuts was not as consistent, indicating a possible need for better control of the cutting edge and gap clearances. Both of these parameters varied over a considerable tolerance band during fabrication of the small quantities of development hardware.

III. DIAPHRAGM DESIGN ANALYSIS

(U) For initial design purposes it was established that:

(U) 1. Regardless of the results of subsequent analysis, the diaphragm would not be less than one mil (0.001-in.) thick. Thinner gages were more difficult to handle and rolling defects are more pronounced.

(U) 2. Available materials data indicate a maximum corrosion rate of 0.0002 in./year for Type 304L CRES foil in either propellant (one mil was added to diaphragm thickness to provide for 5-year storage capability).

(U) 3. An additional one mil was added to the diaphragm thickness for tolerances and blemishes. This produced a "first cut" thickness of three mils.

III, Diaphragm Design Analysis (cont.)

(U) 4. It was predicated that the shearing operation would not be a true punch and die operation and that the fixed part of the sheared diaphragm could be bent up at 90° during the valve closing stroke. This bent portion would have to be cleared on the valve closing operation. Clearance to prevent possible jamming of the gate on closure, including manufacturing tolerances, produced a possible unsupported section of the diaphragm of some 0.045 in.

(U) 5. A proof pressure of 150 psid was assumed adequate to ensure integrity of the long-term storage seal.

(U) 6. For stress analysis purposes a circumferential unit of length was assumed to be a beam, having a length equal to the unsupported gap, fixed at both ends, and uniformly loaded. A tensile yield of 40,000 psi was assumed for the annealed 304L foil.

(U) 7. On the basis of the above assumptions, the diaphragm thickness required to meet proof pressure stress was

$$t = l\sqrt{\frac{p}{2s}} = 0.045\sqrt{\frac{150}{2 \times 40,000}} \approx 0.00195 \text{ in.}$$

where:

t = diaphragm thickness, in.

p = uniform pressure, psig

l = unsupported diaphragm length (gap), in.

s = tensile yield strength, psi (bending)

(U) Allowing one-mil thickness for corrosion a thickness of three mils (0.003 in.) was selected and was used in the demonstration hardware.

(U) As an observation, it was found that the gate on closing does not strike the fixed portion of the sheared diaphragm.

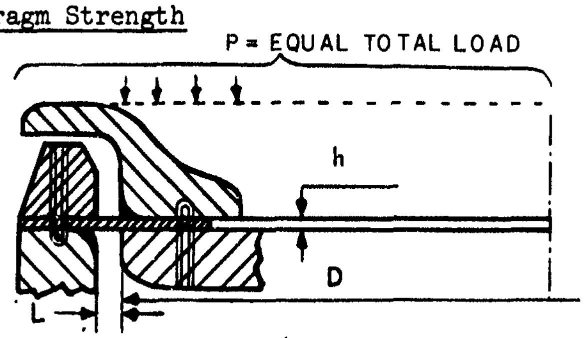
III, Diaphragm Design Analysis (cont.)

(U) Further analysis of diaphragm design must consider the assembly and welding of the diaphragm into the suction valve. Report FSC66-246 included in this appendix describes in detail the order of weldments and the procedure of prestressing the diaphragm prior to the last weldment. The purpose of the prestressing was to assure that the valve gate and attached diaphragm cutter would not deflect under the static storage pressure of the propellants and prematurely cut the diaphragm.

(U) An "Analysis of Diaphragm Strength" supporting the preloading of the foil seal at assembly is shown below. The radii on the inlet sleeve and on the gate as well as the clearance between the inlet sleeve and gate were based on this analysis. The preload applied during assembly was 550 $\pm$ 25 lb which was sufficient to ensure the gate deflection under pressure load would not exceed 0.001 in.

(U) In the preloaded condition, all the slack caused by cams, rollers, and bearing fit-ups has been removed and the diaphragm is deflected away from the diaphragm cutter. Loading the valve with propellant pressure will cause the valve gate to deflect slightly but only in the sense that a preloaded bearing will deflect slightly when rated load is applied. This deflection will reduce the tensile loading in the diaphragm simultaneously as bending stresses due to propellant pressure loading are increased.

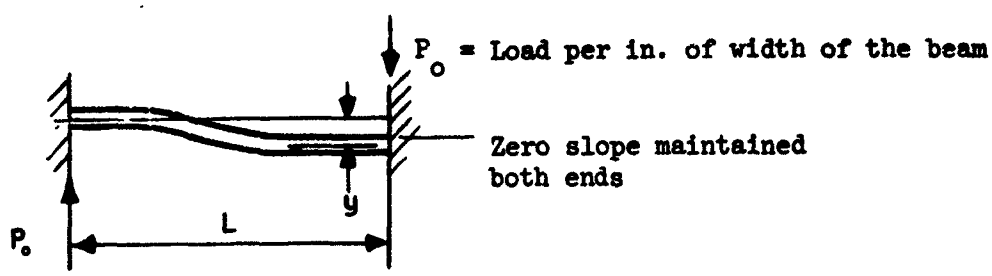
Analysis of Diaphragm Strength



Assume;
h = 0.003 in.
D = 3.35 in.
Material: 304 SS

To establish the required relation L/h, consider the mechanics of a relatively wide beam on sinking support together with the elementary theory of drawing thin, shallow shells.

III, Diaphragm Design Analysis (cont.)



For a conventional beam on sinking supports the deflection of one end with respect to the other is:

$$y = \frac{P_o L^3}{12\ E\ I} \qquad \text{(Eq 22)}$$

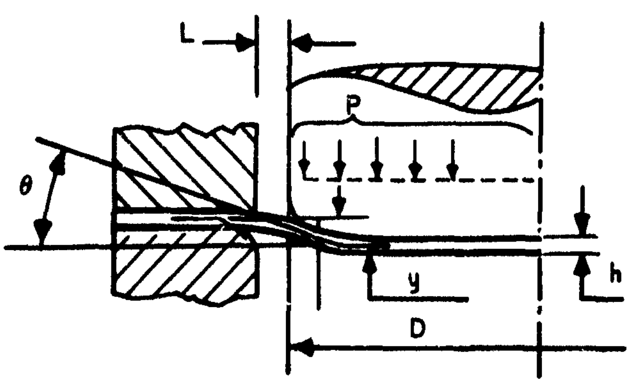
For a relatively wide beam of a rectangular cross-section of unit width, Equation 22 becomes

$$y = \frac{(1-\gamma^2)\ P_o\ L^3}{E \quad h^3} \qquad \text{(Eq 23)}$$

here γ = Poisson's ratio

h = Depth of beam, in.

E = Modulus of elasticity, psi



Analogy to shallow drawing process

The total force on the punch to produce dishing of the diaphragm proportional to angle of incidence, θ , may be approximated as follows:

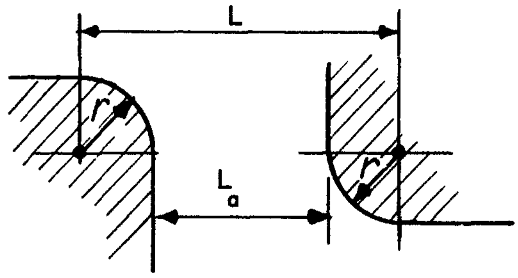
III, Diaphragm Design Analysis (cont.)

$$P = \pi D h S_y \sin\theta \qquad \text{(Eq 24)}$$

As the first approximation take

$$y = L \sin\theta \qquad \text{(Eq 25)}$$

In the above equations L represents the total working clearance which actually includes corner radii. The assembly clearance L_a can therefore be defined as follows:



$$L_a = L - 2r$$

From Equations 23, 24 and 25, follows that:

$$\frac{L}{h} = 1.05\sqrt{\frac{E}{S_y}} \qquad \text{(Eq 26)}$$

Taking S_y = 40,000 psi for SS304 (Metals Handbook, Page 503, curve of stress versus temperature) and $E = 30 \times 10^6$ psi, Equation 26 yields:

$$\frac{L}{h} = 1.05\sqrt{\frac{30 \times 10^6}{40 \times 10^3}}$$

$$\frac{L}{h} = 28.8$$

III, Diaphragm Design Analysis (cont.)

Hence for a diaphragm thickness h = 0.003, we get:

$$L = 28.8 \times 3 \times 10^{-3}$$
$$L = 86.4 \times 10^{-3}$$

Assuming corner radius r = 0.030 in., the assembly clearance becomes:

$$L_a = (86.4 - 2 \times 30)10^{-3}$$
$$L_a = 26.4 \times 10^{-3} \text{ in.}$$

Equation 24, together with Equation 25 becomes:

$$P = \frac{\pi \; D \; h \; yS_y}{L} \qquad \text{(Eq 27)}$$

Hence for

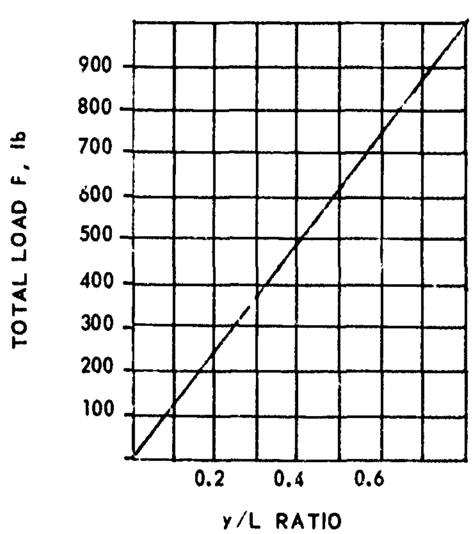
$D = 3.35$ in.

$h = 0.003$ in.

$S_y = 40{,}000$ psi

$$P = 3.14 \times 3.35 \times 3 \times 10^{-3} \times 40 \times 10^3 \; \left(\frac{y}{L}\right)$$

$$P = 1260 \; \left(\frac{y}{L}\right) \qquad \text{(Eq 28)}$$



IV. ELECTRON BEAM WELDING OF SUCTION VALVES

(U) A number of simulated joints on the ARES suction valves were electron beam welded to develop welding parameters and to check out fixturing. The welded joints were leak tested and examined metallographically to determine weld integrity. Weld procedures established from this development were then used in the welding of four ARES suction valves. Valve SN 000005 passed cyclic leak tests using 100 psig helium pressure in the internal inlet cavity and vacuum from 75 to 48 microns externally for 110 cycles.

A. ELECTRON BEAM WELDING SEQUENCE

(U) A number of test specimens simulating the weld joints of the suction valves were electron beam welded and evaluated. Three different weld joints were involved on the ARES suction valves. The material was Type-304 stainless steel for all electron beam welded components.

(U) Weld 1 joins a 0.003-in.-thick diaphragm between a retaining ring (PN 1129235) and the inlet sleeve (PN 1129237) to make the sleeve assembly inlet (PN 1129238).

(U) Figures II-2 through II-5 show the weld fixture, a welded assembly in the weld chamber and helium leak testing set-ups of the inlet sleeve assembly. The fixtured parts as shown in Figure II-3 were preheated to 400°F prior to welding. Through experimentation it was discovered that pre-heating of the part prior to welding reduced wrinkling of the diaphragm and shrinkage of the inlet sleeve. Average shrinkage of the inlet sleeve at the diaphragm was 0.003 in. when the part was preheated prior to welding compared to 0.007 in. shrinkage when preheat was omitted. The electron beam weld gun was positioned 10 degrees from the plane of the weld as shown in Figure II-3. The weld, Figure II-6, was found to be sound and passed the helium leak tests. The weld shown in Figure II-7 is a cross section of a weld which failed the helium leak test. The internal void at the diaphragm junction allowed helium passage

IV, A, Electron Beam Welding Sequence (cont.)

around the diaphragm through the void. Weld repairs were made on two inlet assemblies by raising the electron beam weld gun 0.010 in. and then rewelding using the same weld schedule as for the initial weld except preheat was not applied. The retainer rings of weld test pieces were 0.100 in. thick; however, the thickness was reduced to 0.060 in. for production parts for valve functional purposes. This reduction of retainer ring thickness required extreme caution to prevent excessive distortion during repair welding of the joints. The weld parameters for Weld 1 were as follows:

Gun to work distance, in.	2-1/4
Beam current, ma	54
Accelerating voltage, kv	28
Focus current, amp	4.7
Filament current, amp	50
Rate of weld travel, ipm	100

(U) All inlet sleeve assemblies passed the helium leak test prior to assembling into the next higher assembly to make Weld 2.

(U) Weld 2 joined the cutter holder and inlet sleeve assembly to the valve gate. The weld pierced the cutter holder and diaphragm fusing both members to the valve gate. Figures II-8 through II-11 show the cutter and holder, inlet sleeve assembly, the part fixtured for welding, and the helium leak testing of Weld 2. In assembling the inlet sleeve and cutter assembly extreme care was required to avoid rupturing the 0.003-in.-thick diaphragm. Dimensions were taken of the cutter OD and the inlet sleeve ID to determine radial clearances. Shims were then placed to center the cutter in the inlet sleeve assembly prior to fixturing for welding to maintain uniform clearance. The hat section of the weld fixture was uniformly torqued into position by three bolts to assure positive contact between members prior to welding Joint 2. The electron beam weld schedule for this joint was as follows:

IV, A, Electron Beam Welding Sequence (cont.)

Gun to work distance, in.	2-1/2
Beam current, ma	80
Accelerating voltage, kv	38
Focus current, amp	5.4
Filament current, amp	53
Rate of weld travel, ipm	100

The No. 2 welds were helium leak tested prior to making the final weld by applying vacuum in the inlet sleeve cavity and helium around the valve body as shown in Figure II-11.

(U) Weld Joint 3 consisted of a seal weld joining the top inlet sleeve assembly to an insert in the valve body. The insert contained a Teflon O-ring on the OD and was shrunk fit into the aluminum valve body.

(U) Test specimens simulating Joint 3 were machined and electron beam welded. The stainless steel insert was machined to have 0.004-in. interference fit with the aluminum ring. To assemble the insert into the aluminum ring, the aluminum wa heated to 300°F then placed over the insert and quenched in water to prevent plastic flow of the Teflon O-ring. The inner ring, simulating the inlet sleeve, was then assembled and welded. Figures II-12 through II-15 show one of the test specimens as welded after removal of the insert from the aluminum ring and cross sections of the electron beam weld. The Teflon O-ring retained its sealing capability after welding which was demonstrated by helium leak testing the joints after welding.

IV, A, Electron Beam Welding Sequence (cont.)

(U) The electron beam weld schedule used for the simulated and No. 3 valve welds was as follows:

	Sealer Pass	Penetration Pass
Gun to work distance, in.	4-1/2	4-1/2
Beam current, ma	55	95
Accelerating voltage, kv	12	17
Focus current, amp	3	3.5
Filament current, amp	53	53
Rate of weld travel, ipm	55	55

(U) Prior to welding the No. 3 joint, the valve was fixtured and loads were applied to the valve gate (shown by the vertical arrow in Figure II-16) to determine the preload force required to eliminate the major (low spring rate) deflection of the valve gate. This deflection of the valve gates varied from 0.002 to 0.005 in. due to machining, cam and shaft bearing tolerances. A bolt and thrust bearing assembly shown in Figure II-17 was calibrated to apply the necessary pre-load to the inlet sleeve assembly to eliminate the major deflection of the valve gates prior to welding Joint 3. Preloading of the inlet sleeve assembly prevented the knife shearing the diaphragm due to valve gate deflection.

(U) Force values and major gate deflections of the four valves welded were as follows:

Valve SN	In.-lb Torque	Pounds Force	Max Gate Deflection
005	60	585	0.005
003	50	525	0.003
002	50	525	0.002
004	60	585	0.003

IV, A, Electron Beam Welding Sequence (cont.)

Figure II-16 shows a valve body with the inlet sleeve assembly and cutter in place along with the compression plug and the thrust bearing. The arrow at the periphery of the inlet sleeve joint indicates the location for Weld 3. During welding of Weld 3, the fixtured valve is rotated in the clock-wise direction while the compression fixture remains stationary as shown in Figure II-17. The arrow shows the line of the welding beam bypassing the fixture cross-head. The optical system used to align the electron beam with the joint is shown at the lower right of the welding gun. The tie wire through the shaft at the lower left of the valve body held the valve gate in the closed position and prevented gate motion during welding and leak testing.

(U) After welding of Joint 3 on all valves was completed, the finished valves were helium leak tested. Preliminary leakage testing utilized vacuum in the inlet sleeve cavity and localized helium flow through a probe between the fixture and the valve body shown by an arrow in Figure II-18. This test verified leak tight welds at Joint 3.

(U) The final leak test of the valves was accomplished by pressurizing the inlet sleeve cavity with helium at 100 psig and drawing a vacuum of 75 to 48 microns on the ID and OD of the valve body in the bell jar shown in Figure II-19. In addition to the leak tests mentioned Valve SN 000005 received a qualification test for 110 cycles with pressure reversals of 100 psig helium in the inlet sleeve cavity and constant vacuum of 75 to 48 microns internally and externally. Valve SN 000005 showed no evidence of leaks after the qualification tests. The other three valves passed the contractual leakage requirements.

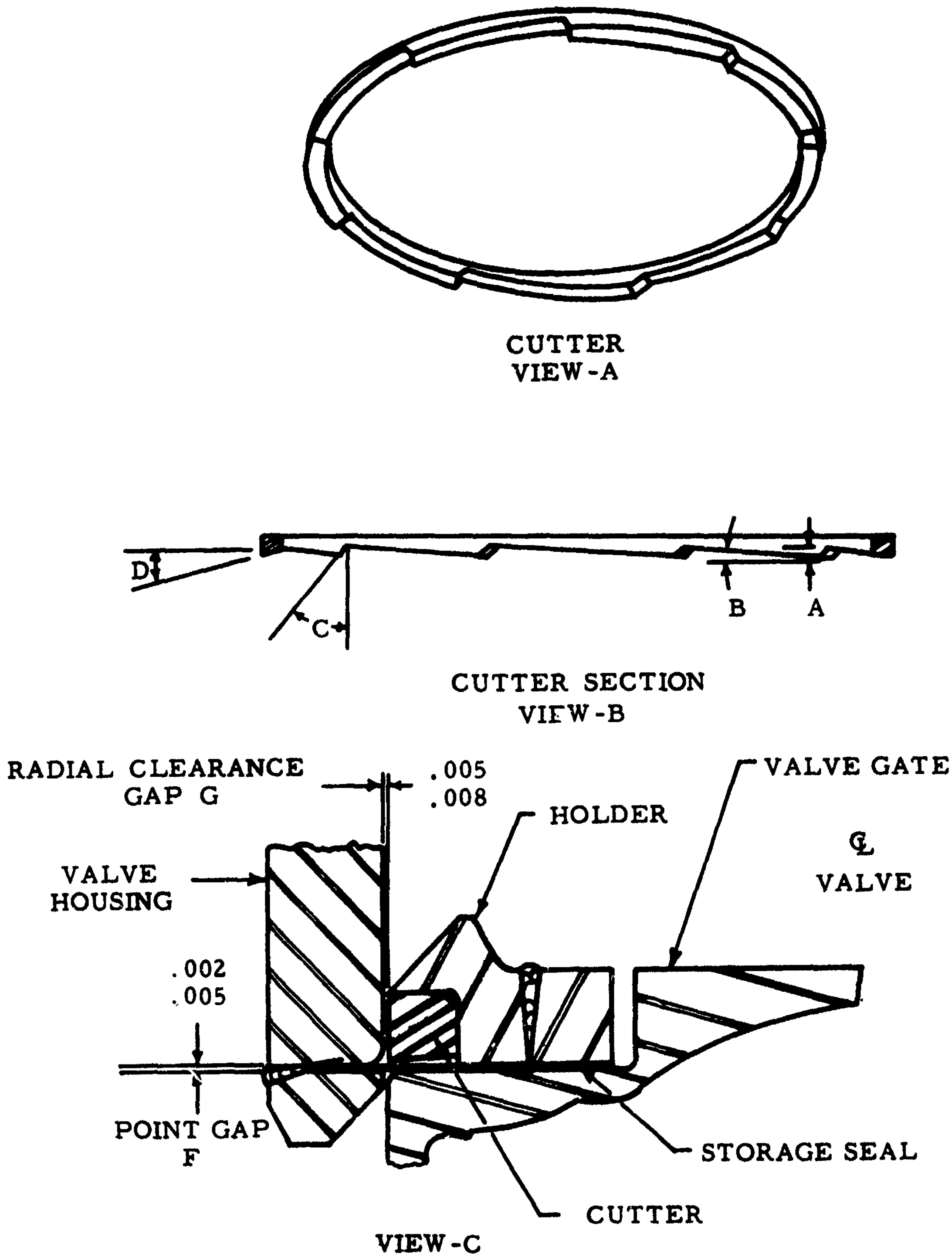
B. CONCLUSIONS

(U) Suction valves having a shear diaphragm can be successfully electron beam welded with a high degree of reliability to pass the leakage requirements of the work statement.

IV, Electron Beam Welding of Suction Valves (cont.)

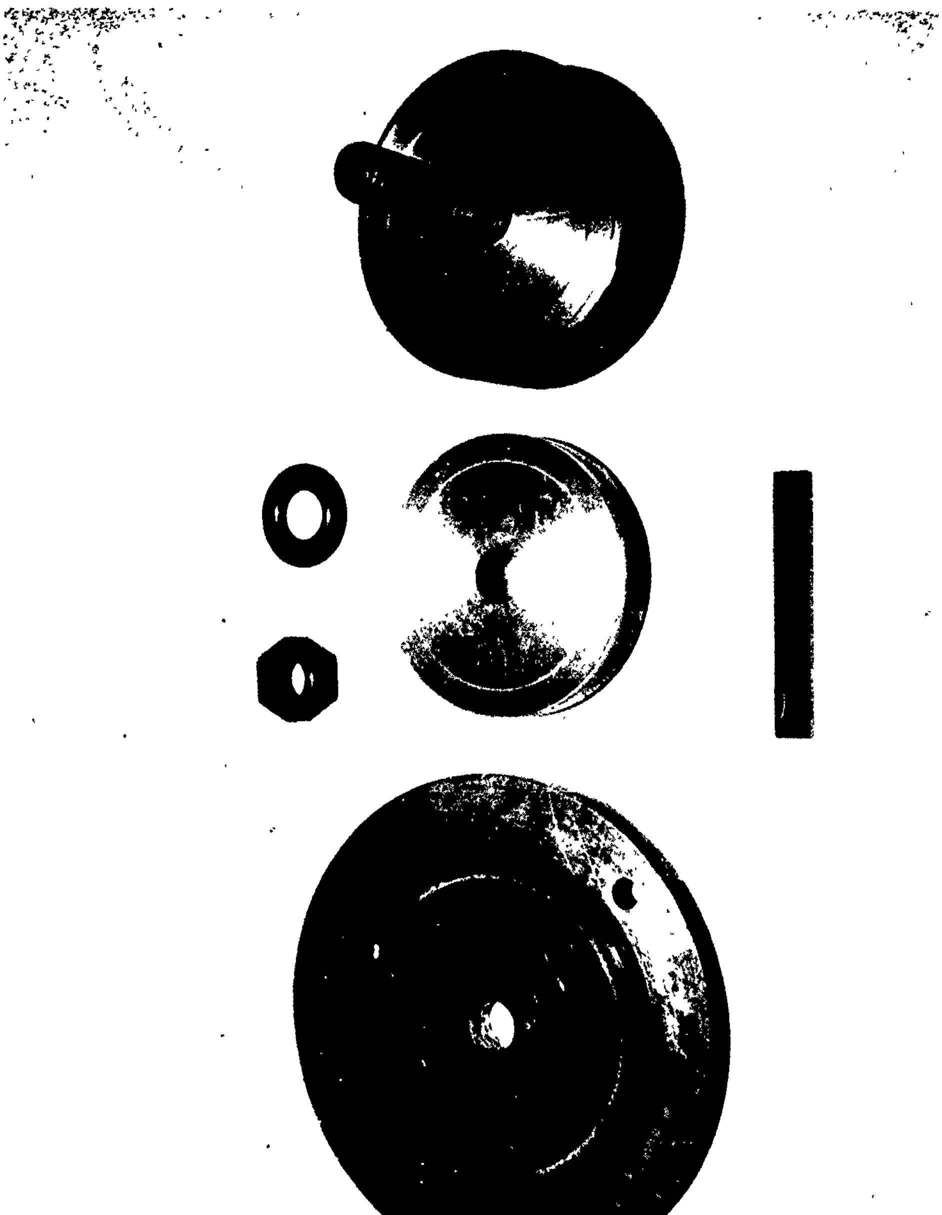
C. RECOMMENDATION

(U) Leave machining stock on the retainer rings for final machining after the welded subassemblies have passed helium leakage tests to reduce the possibility of distortion during welding.



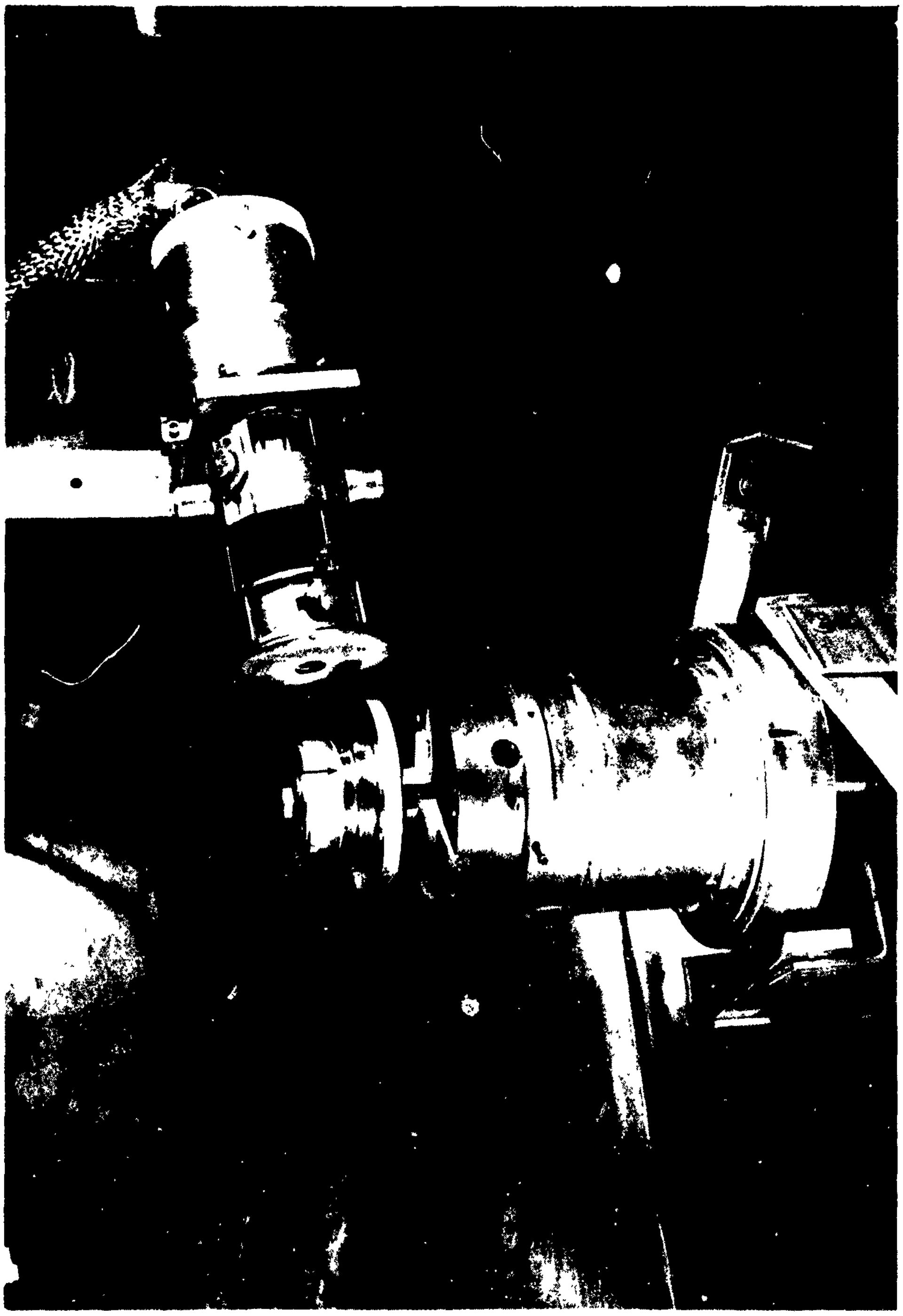
Cutter and Storage Seal Configuration

Figure II-1



Fixture Used to Locate PN 1129237-1 Sleeve Inlet, 1129236-1 Diaphragm, and 1129235-1 Retaining Ring During Electron Beam Welding to Make PN 1129238, Sleeve Assembly Inlet

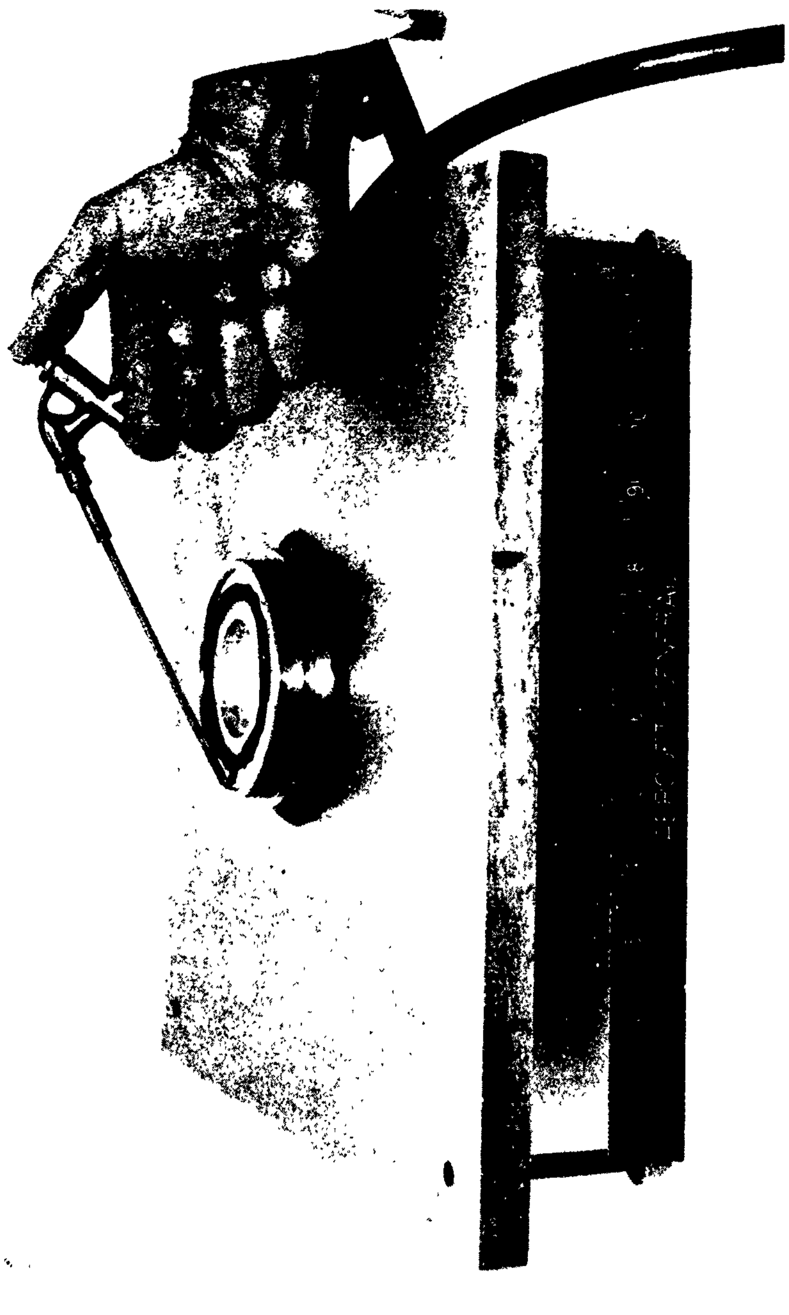
Figure II-2



PN 1129238 Sleeve Assembly Inlet, Fixtured in the Electron Beam Weld Chamber

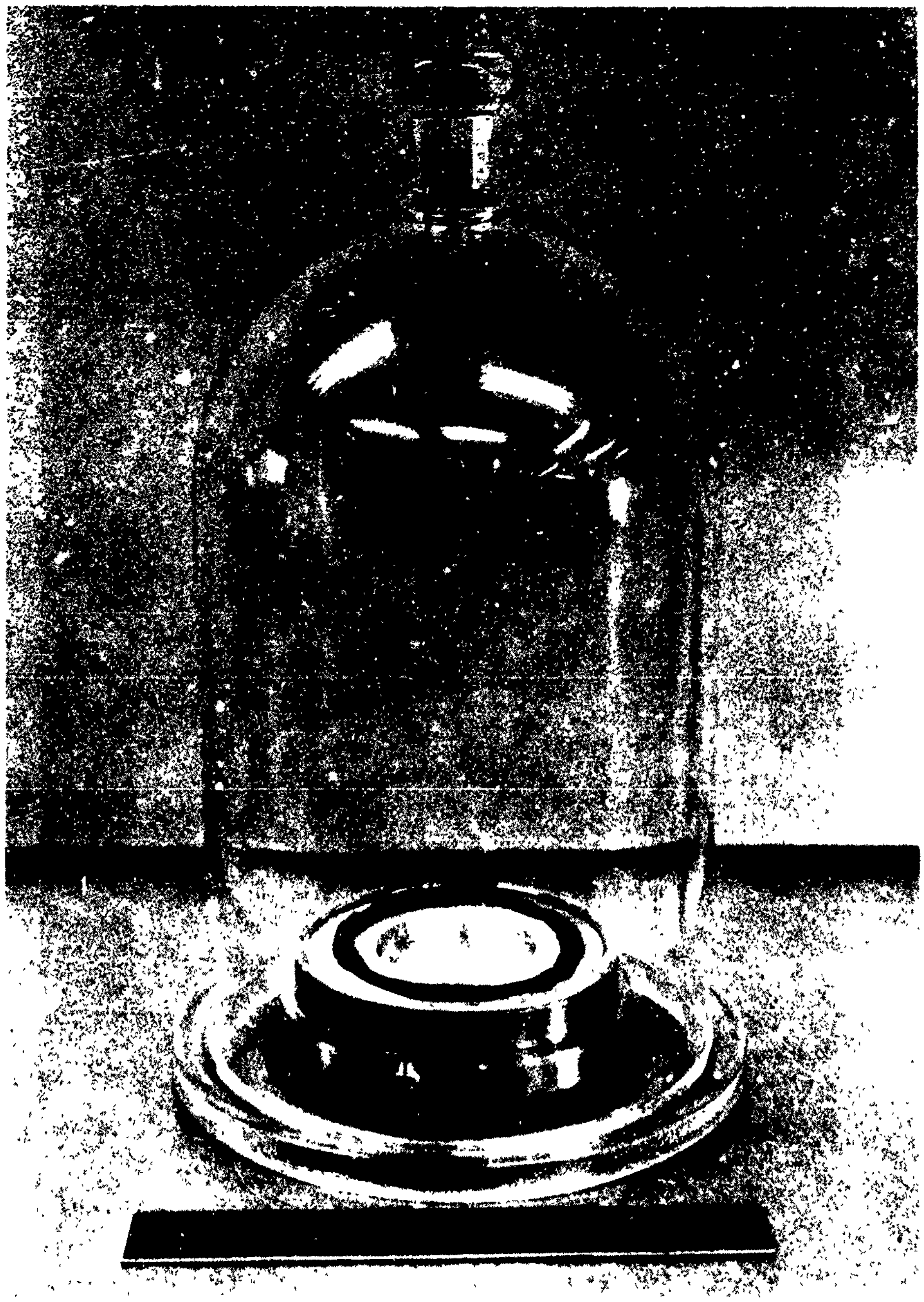
No. 1 weld has been completed as shown by the arrow. The part is rotated in the clockwise direction during welding. The electron beam gun is set 10° from the horizontal plane to weld this joint.

Figure II-3



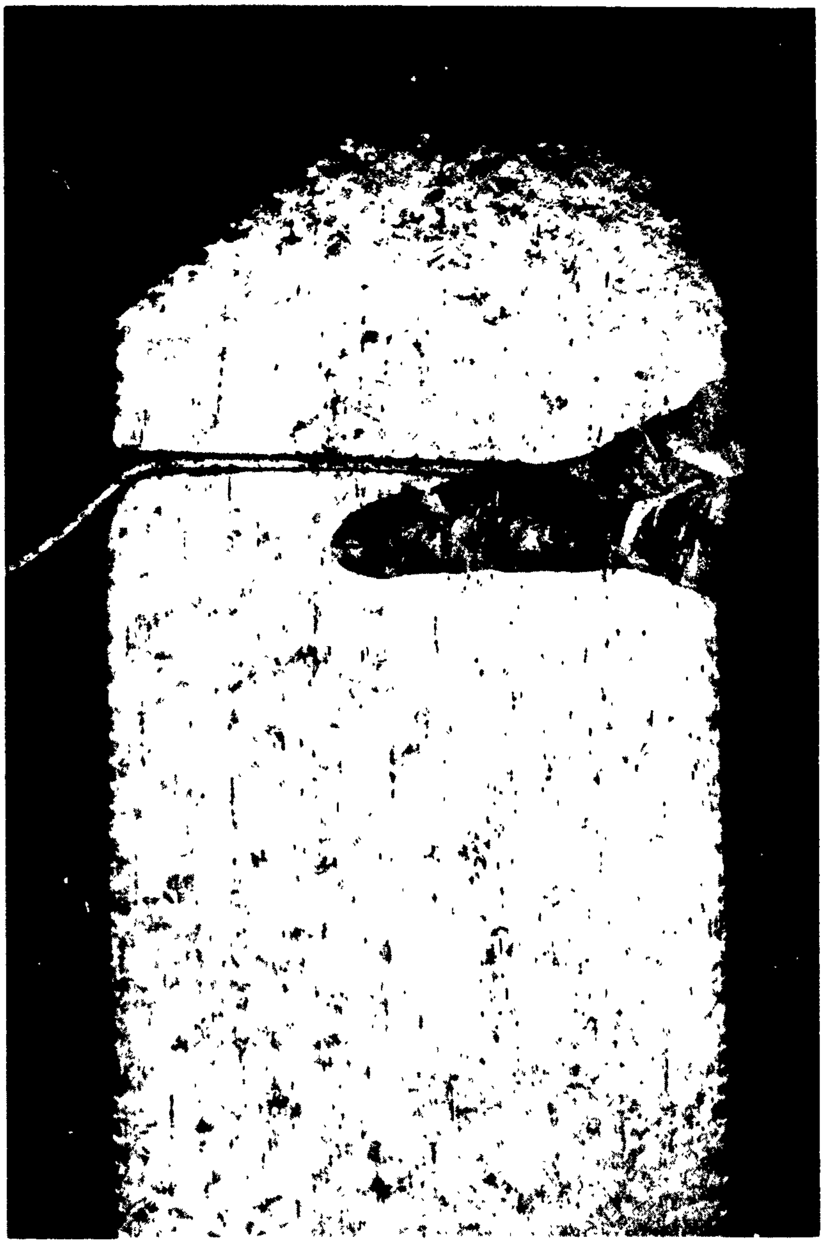
Helium Leak Testing Weld No. 1 of the Welded Inlet Sleeve Assembly

Figure II-4



Helium Volume Leakage Tests by Applying Vacuum to the Inner Cavity and Helium on the Outer Surface in the Glass Jar

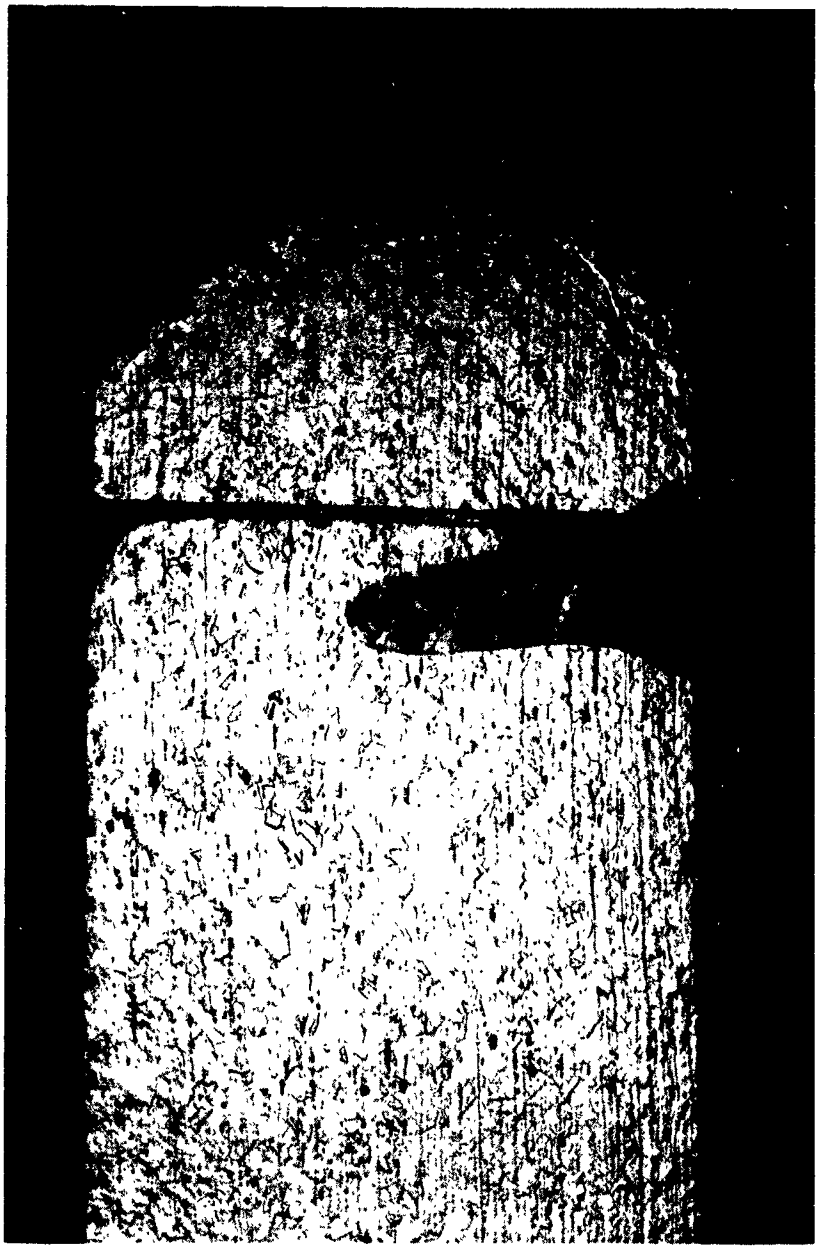
Figure II-5



Sound Weld No. 1 Joining the 0.003-in.-Thick Diaphragm Sandwiched Between the Retainer Ring and the Inlet Sleeve

The weld was made using the weld schedule described in this report. The retaining ring of this test specimen was 0.100-in.-thick. The thickness was reduced to 0.060 in. for production parts.

Figure II-6



Photomacrograph of a Weld No. 1
Taken from an Area Where Leakage was Detected by the Helium Leak Tests

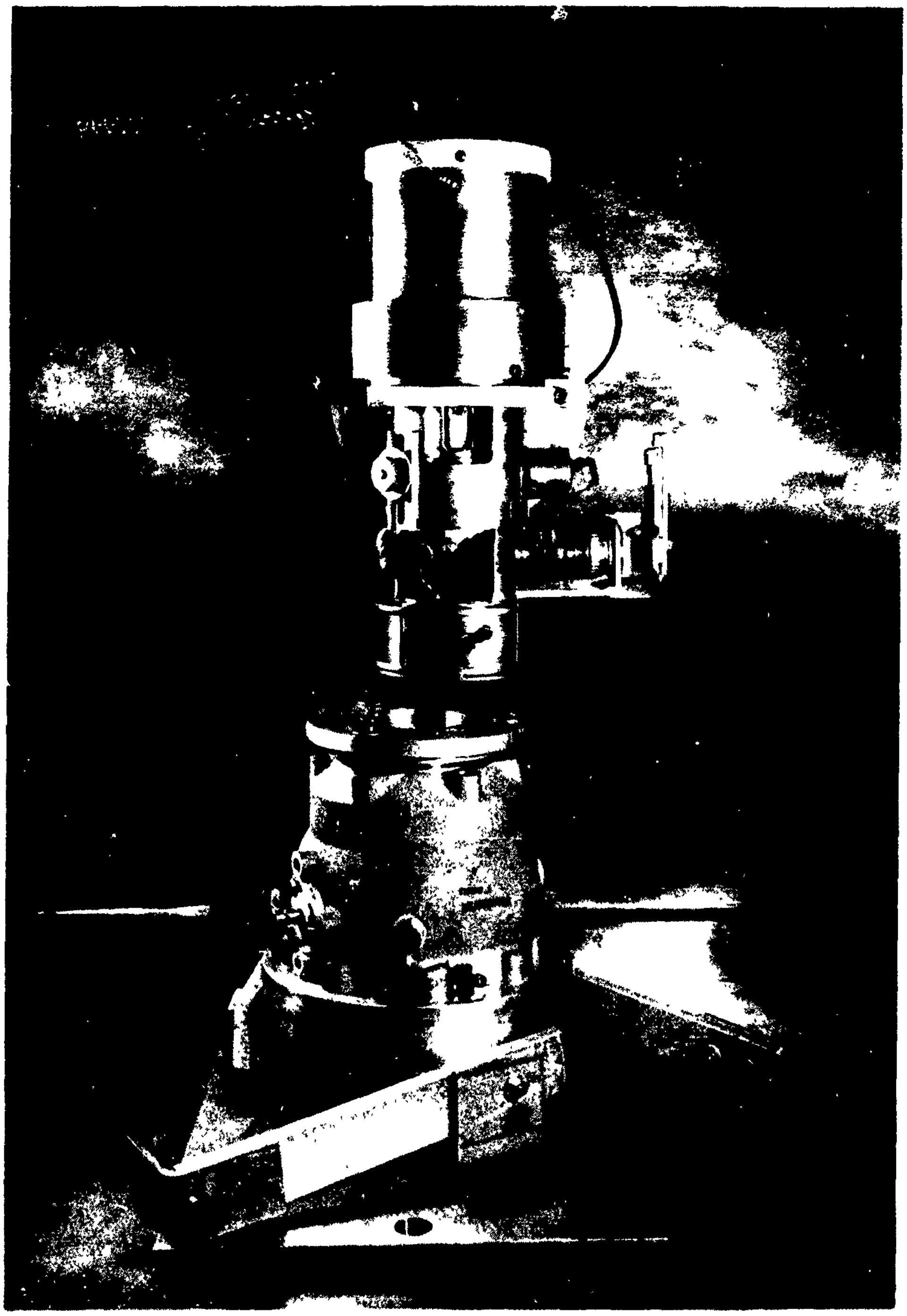
Figure II-7

Welded Sleeve Assembly Inlet, Retaining Ring, and the Diaphragm Cutter Assembly

Figure II-8

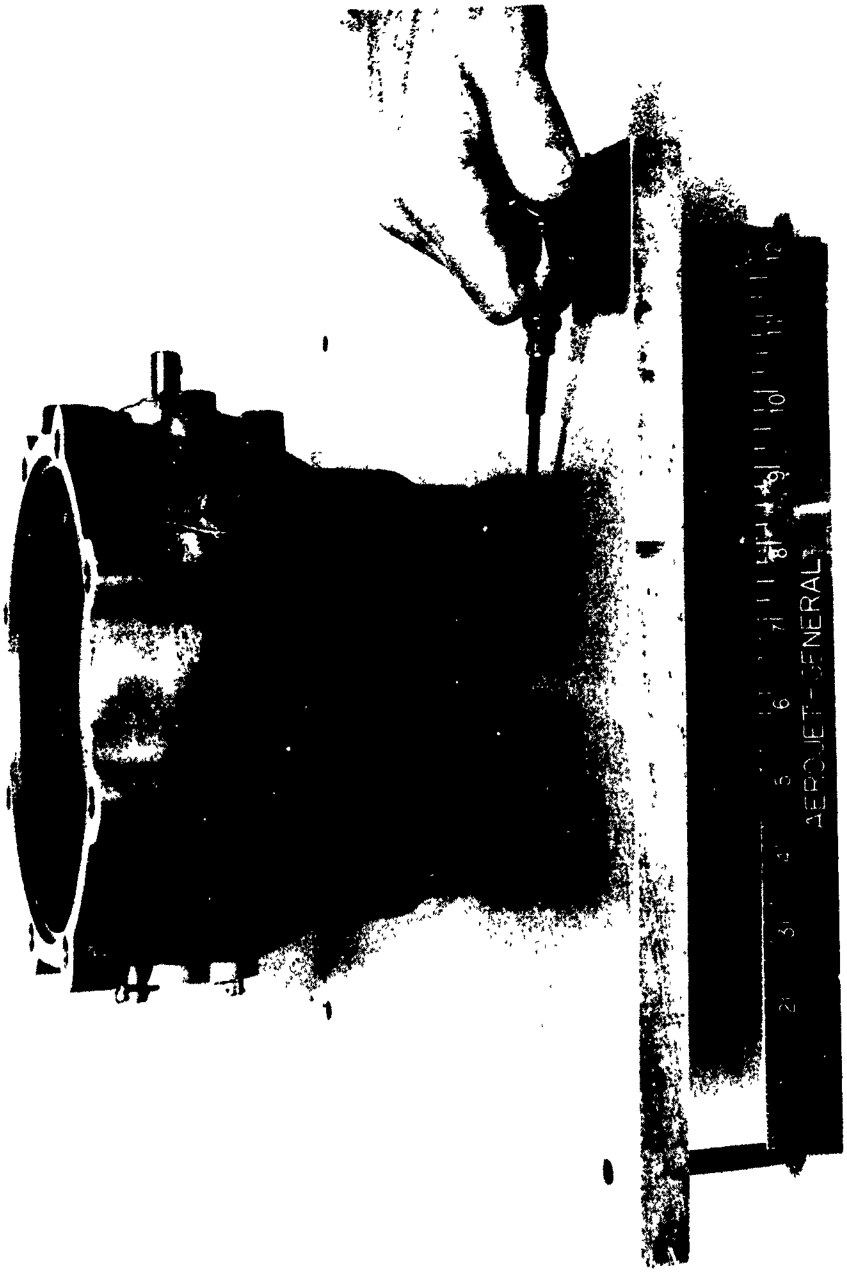
Suction Valve Body Along with a Welded Sleeve Assembly and Weld Fixture

Figure II-9



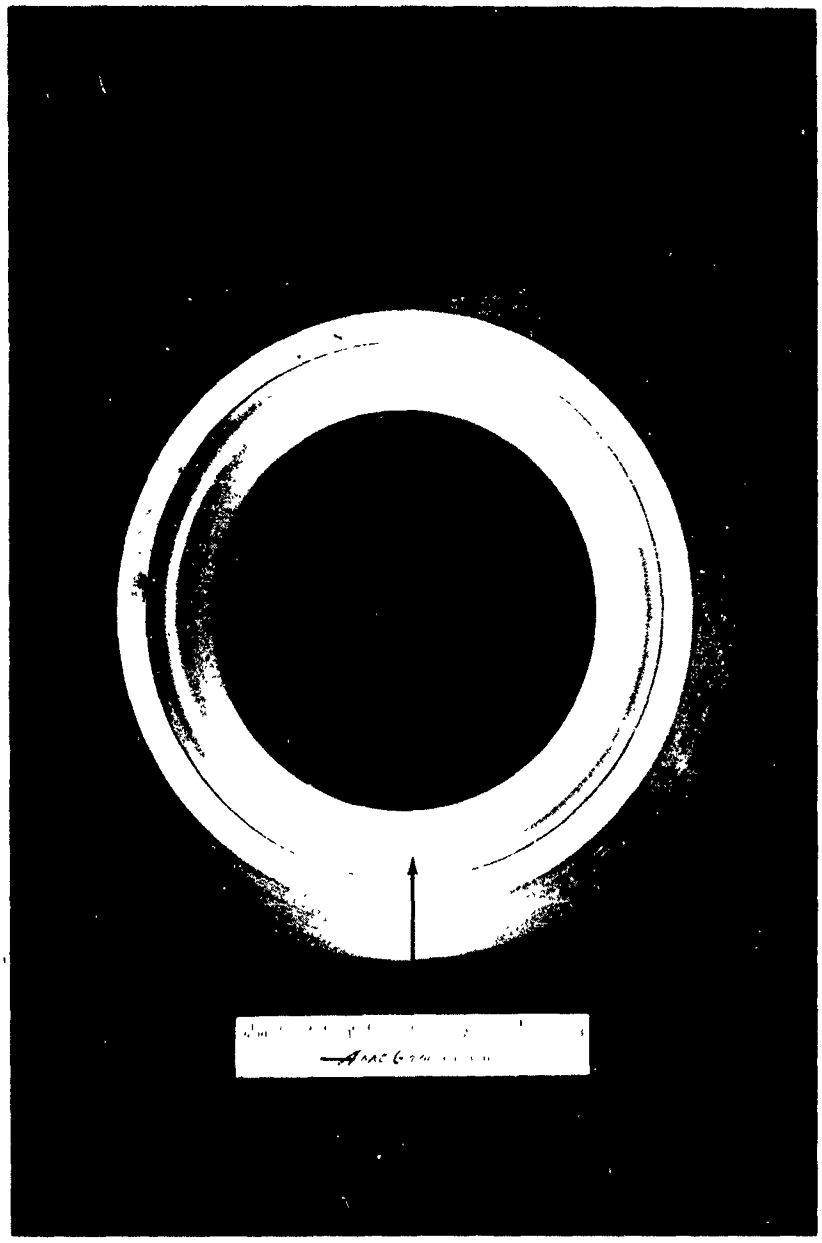
The Suction Valve with the Inlet Sleeve Assembly Assembled and Fixtured for Electron Beam Welding of Weld Joint No. 2

Figure II-10



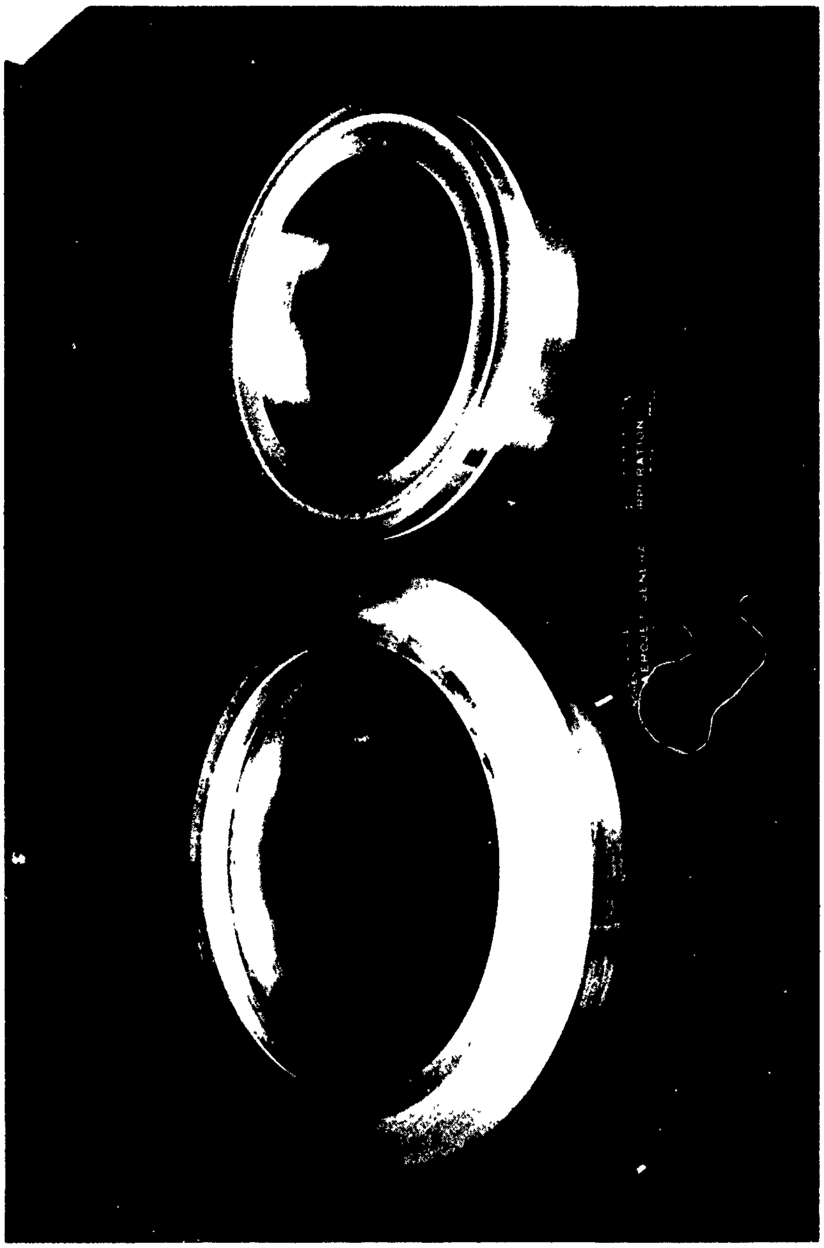
Helium Leak Testing of Weld Joint No. 2

Figure II-11



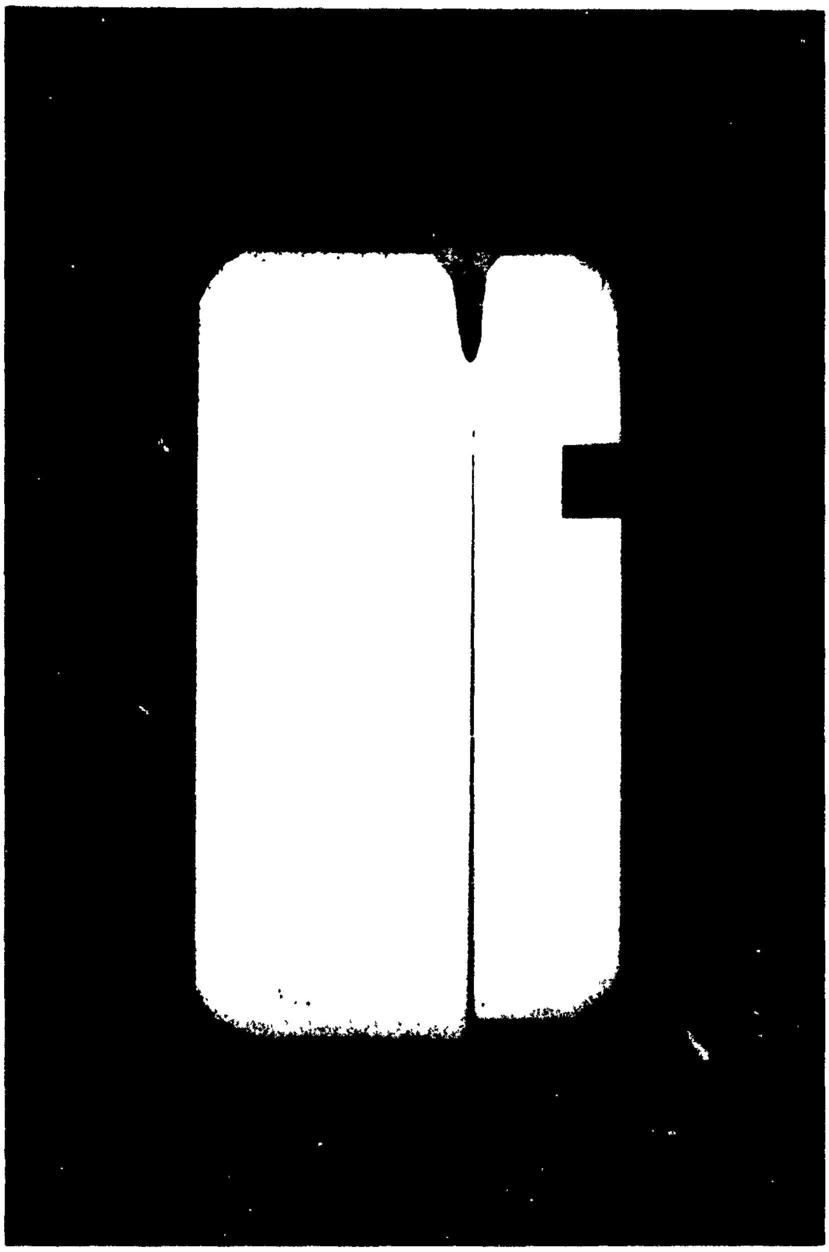
A Test Specimen Simulating Weld Joint No. 3
The electron beam weld is shown by the arrow.

Figure II-12



A test specimen simulating joint No. 3 after removal of the aluminum outer ring. Forces required to remove the outer ring were 1550 and 1900 lb. Examinations of the Teflon O-ring showed no adverse effects from the heat input from the welding operation.

Figure II-13

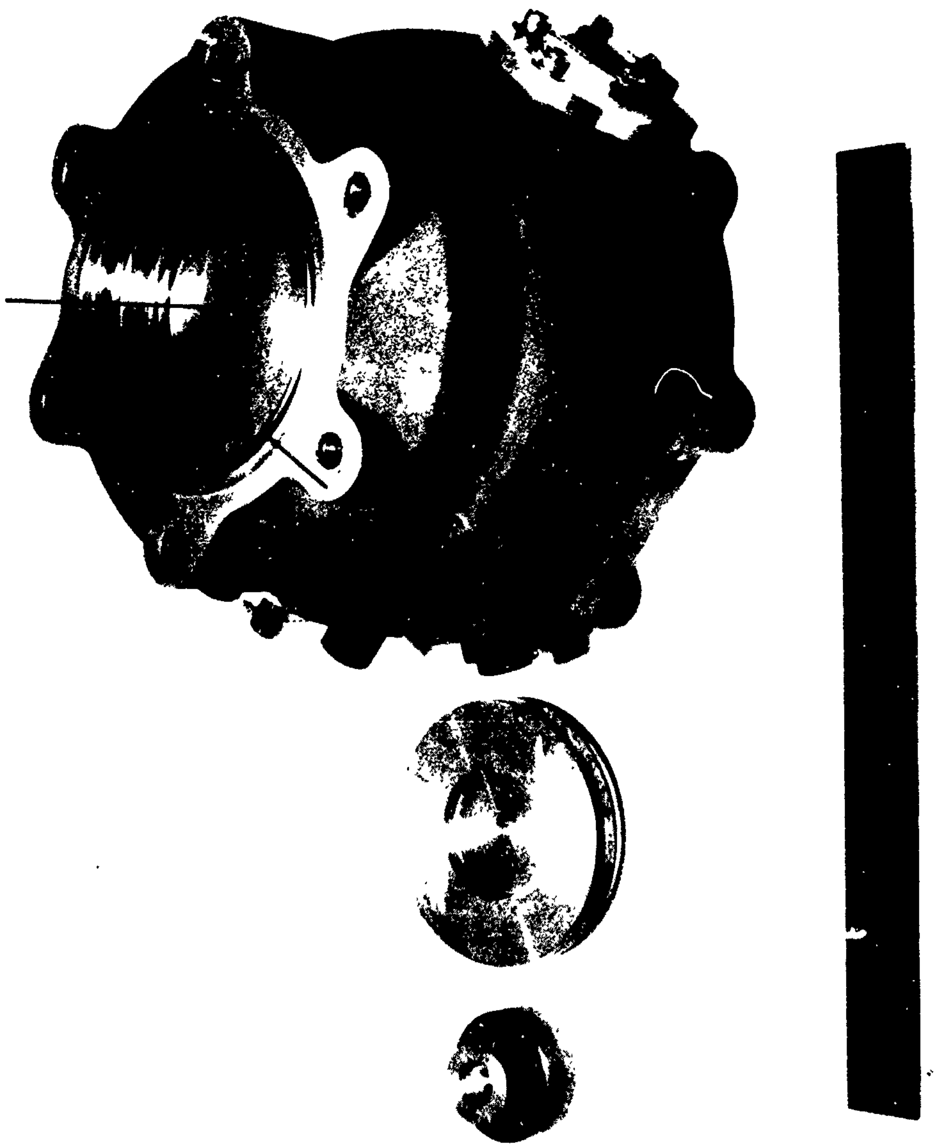


Photomacrograph of an electron beam weld of joint No. 3 produced by the weld schedule discussed in the text of this report. The depth of weld penetration was 0.153 in.

Figure II-14

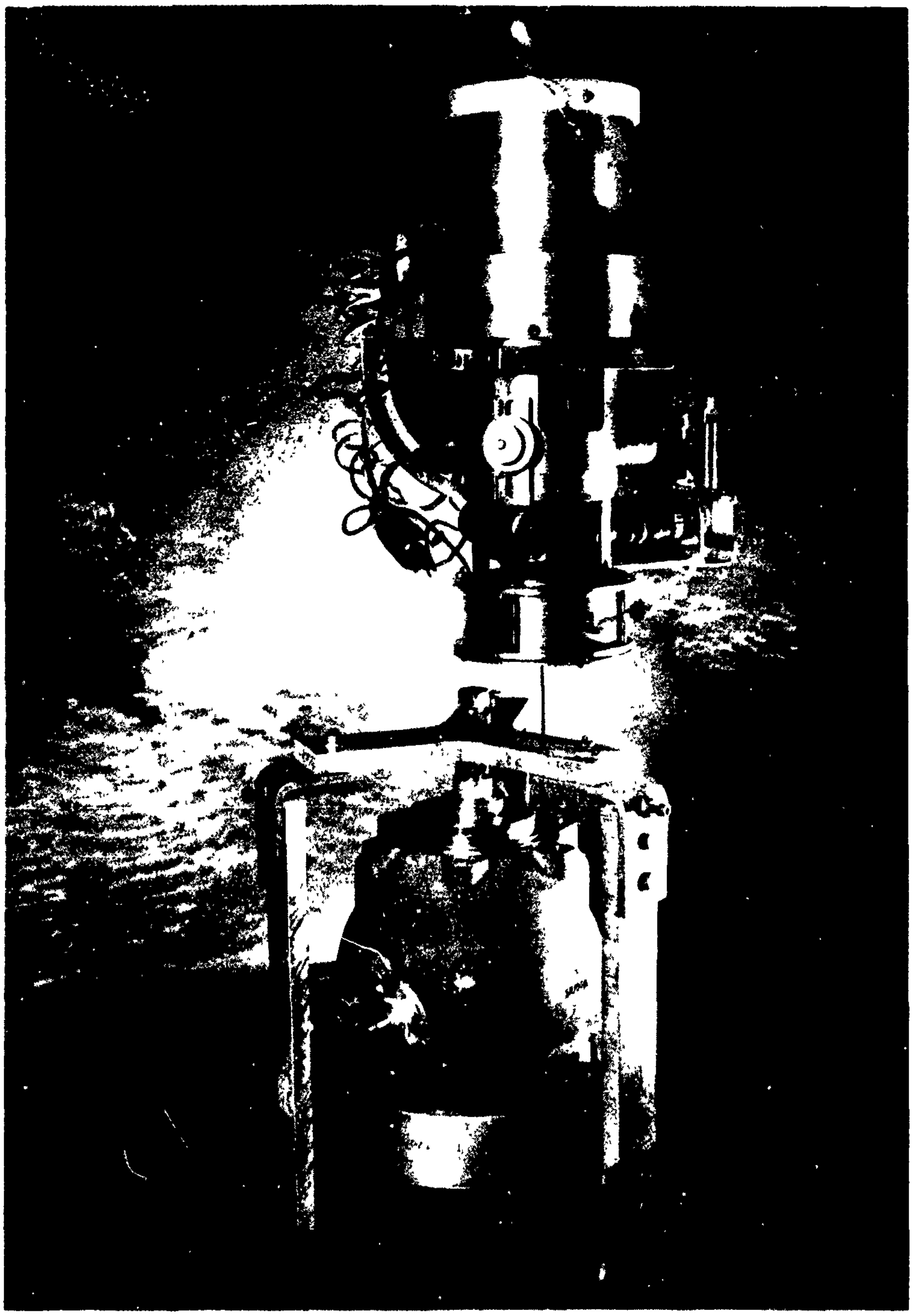
A photomicrograph taken at the nail head of the electron beam nugget. The weld was sound which was typical of all weld areas examined.

Figure II-15



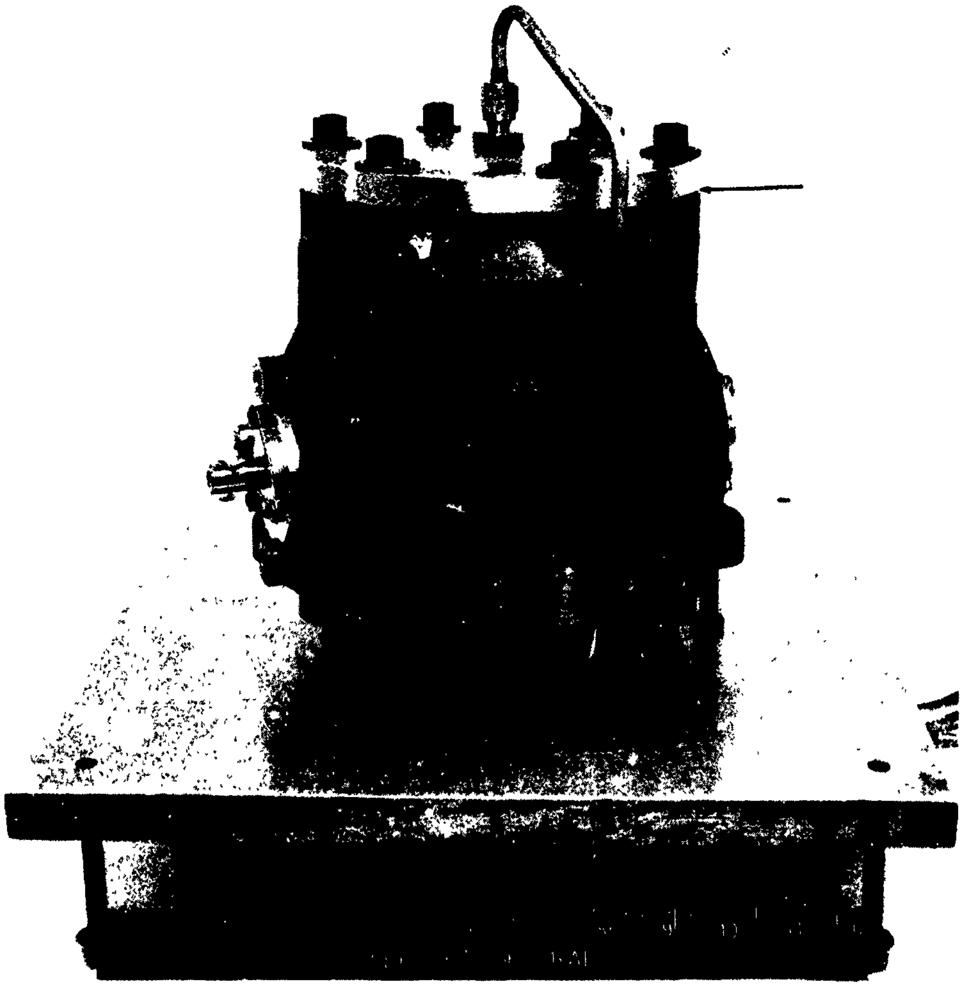
Inlet Sleeve and Cutter Assemblies in Place; Also the Compression Loading Plug and Thrust Bearing

Figure II-16



Suction Valve Fixtured for Electron Beam Welding of Weld Joint No. 3

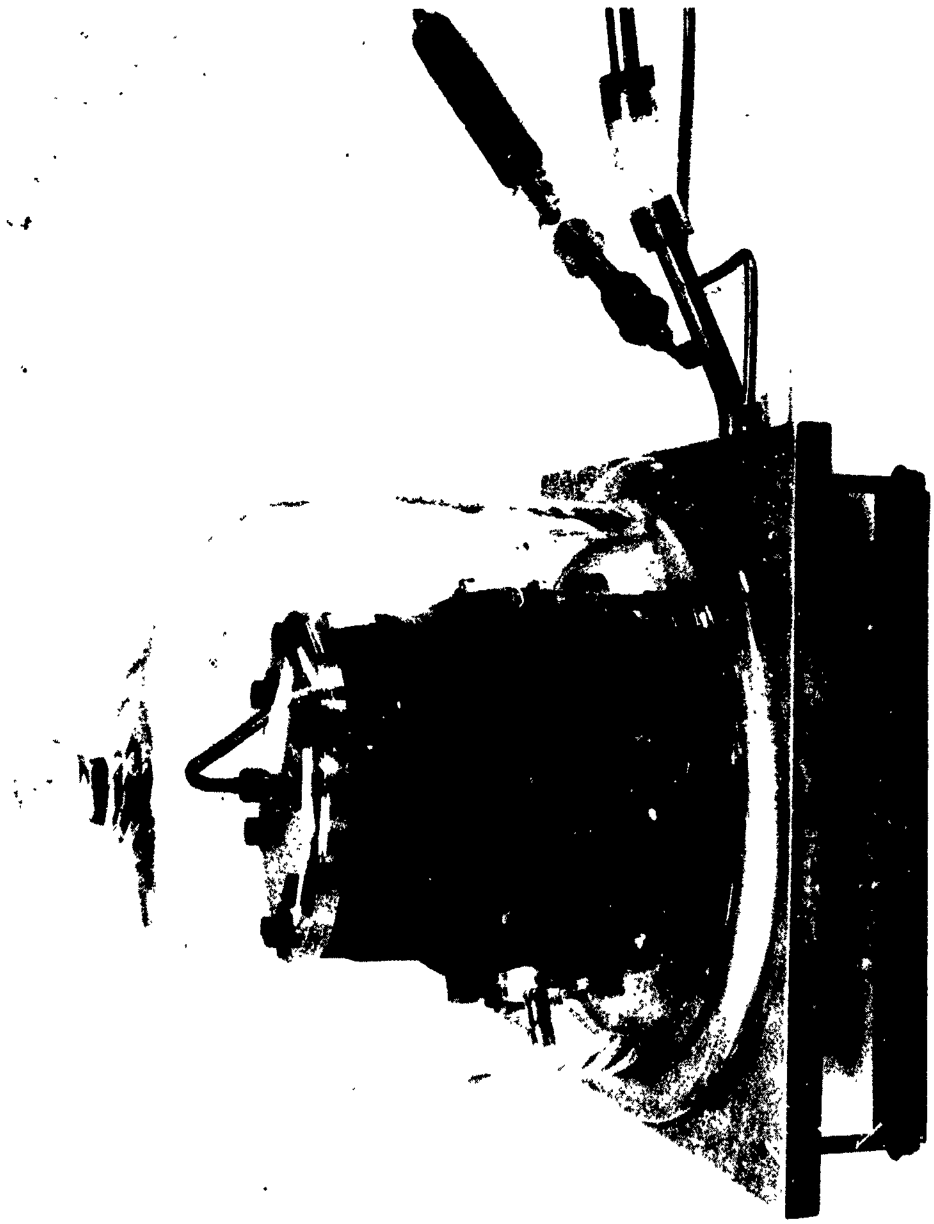
Figure II-17



Preliminary Helium Leak Testing a Completed Suction Valve

Figure II-18

UNCLASSIFIED



Final Helium Leak and Cyclic Testing of a Completed Suction Valve

Figure II-19

UNCLASSIFIED

FIGURE LIST

FIGURE LIST

A. SUMMARY

1. Accomplishments

(U) The Phase I advanced-propellant design evaluation program was completed. The ARES module design as defined in September 1965, and shown in Figure III-1 of this appendix, was evaluated to determine the changes that would be required to accommodate three specific sets of advanced propellants.

2. Technical Results

(U) Results of this study showed that conversion of the ARES module to the use of advanced propellants at the 100,000-lb thrust level would change the flow schedule of the module significantly. Major components were classified as to their usability in the conversion, as follows: (1) could be used directly with no design change, (2) could be used directly with recommended design changes, (3) could be used after rework, and (4) cannot be used and must be resized to be satisfactory.

(U) The following ARES components were established as being usable with no design change:

(1) Boost pumps*

(2) Suction lines*

(3) Suction valves*

(4) Primary combustor fuel valve when used for the control valve in the bipropellant primary combustor.

*These items requir: change of location.

A, Summary (cont.)

(5) The turbopump housing design is adequate for two advanced-propellant combinations, N_2O_4/Alumizine 43 and H_2O_2/Alumizine 43. The housing can be made adequate for the third combination analyzed, Compound A/N_2H_4, provided shaft speed is increased, or operating pressure of the secondary combustor is reduced, or the housing is modified to accommodate a larger diameter pump impeller.

(U) Components that can be reworked from the ARES configuration to accommodate a specific propellant are:

(1) The oxidizer impeller

(2) The second-stage fuel impeller (for bipropellant operation only)

(U) The other major components are not acceptable due to the increased fluid flow to the secondary combustor. These components will have to be resized.

(U) Greater convertibility could be achieved by using an N_2O_4/AeroZINE 50 cycle that is based on a fuel-rich rather than an oxidizer-rich primary combustor. However, conversion to this cycle would demand the development of a high-temperature turbine as well as new primary and secondary combustors. Therefore, the fuel-rich primary combustor cycle with N_2O_4/AeroZINE 50 is not recommended in the current program.

Advanced Propellants (cont.)

B. OBJECTIVES AND APPROACH

(U) The objective of the Phase I effort was to establish changes that can be incorporated into the ARES engine so that the engine would be more suitable for use with advanced propellants.

(U) The effort was divided into several tasks, as described below.

1. Propellant and Gas Properties

(U) The transport, combustion, and performance properties were compiled for three sets of propellants: Compound A/Hydrazine*; N_2O_4/ Alumizine 43; and 98% H_2O_2/Alumizine 43.

2. Hydrodynamic Analysis

(U) Promising system cycles were defined and analyzed, considering secondary-combustor cooling and primary-combustor bipropellant and monopropellant operation.

3. Material Selection

(U) The materials in the current ARES designs were reviewed for compatibility with the new environments, with material changes recommended where required. These changes were based on the material surface environments predicted in the hydrodynamic analysis and preliminary heat-transfer analysis.

* (C) The unclassified term "Compound A" will be used throughout this section to denote ClF_5, which is classified.

B, Objectives and Approach (cont.)

4. Heat Transfer

(U) The basic cooling requirements were evaluated with the ARES design and reviewed for compatibility, based on the operating conditions predicted in the hydrodynamic analysis.

5. Predesign Specifications

(U) General and specific criteria were summarized from the hydrodynamic, material, and heat transfer evaluations to derive (1) pressure schedules, (2) a list of acceptable or unacceptable materials, (3) design pressures, temperatures, and flows, and (4) heat-flux data for use by designers to provide advanced-propellant capability in their future designs or redesigns.

6. Design Changes

(U) The current ARES component and module designs were then reviewed and specific changes incorporated where possible to provide capability of future conversion to advanced propellants with the minimum of changes and without compromising the ARES program.

7. Approach

a. Quantitative Analysis

(U) The most promising cycle for each of the propellant combinations were analyzed quantitatively.

b. Emphasis on Major Changes

(U) Emphasis was placed on defining the gross hardware changes required for feasible operation with the advanced propellants.

B, Objectives and Approach (cont.)

c. Performance

(U) Only minimum effort was planned to optimize performance parameters (e.g., chamber pressure, mixture ratio, expansion ratio, and suction specific speeds) since these refinements depend too much on vehicle application and are more appropriate to Phase II of the ARES advanced propellant program.

C. CYCLE DEFINITION

(U) Figure III-1 shows a matrix of the potential use combinations of the advanced propellants, depending on their application as primary combustor propellants and as secondary combustor coolants. Four cases were selected from the combinations as the most promising for extensive analysis within the program's funding and time allocations. Case 1 in Figure III-1 was simply the ARES cycle with N_2O_4 and AeroZINE 50 propellants.* Case 1 was used in the study as the basis for comparison.

(C) Case 2 in Figure III-1 was selected as the most practical mode of operation with N_2O_4 and Alumizine-43. It was similar to the ARES operation in that the bipropellant primary combustor was oxidizer-rich, and the secondary combustor was cooled with N_2O_4. Fuel-rich primary combustor operation was considered to be less practical because of the large amount of molten aluminum in the turbine drive gases. Fuel cooling of the secondary combustor was considered impractical for conventional regenerative cooling without development of a method to obtain turbulent flow in Alumizine-43.

(C) Case 3 was selected for operation with 98% H_2O_2 and Alumizine-43, because H_2O_2 is an effective monopropellant for turbine drive. Test results

*AeroZINE 50 is the Aerojet-General trade name for 50% UDMH + 50% N_2H_4 fuel blend.

C, Cycle Definition (cont.)

from the Advanced Propellant Staged-Combustion Feasibility Program, Contract AF 04(611)-10785, has shown 98% H_2O_2 to be a good regenerative coolant. Use of Alumizine in the turbine drive gas or as a secondary combustor coolant would create problems as discussed in Case 2 above.

(C) Six combinations were considered for the Compound A and Hydrazine blend propellants. Case 4 was selected for analysis and utilizes N_2H_4 both as a monopropellant for the primary combustor and as the coolant in the secondary combustor. Hydrazine (N_2H_4) was selected for the major part of the analysis in place of a more stable blend, such as MHF-3 or MHF-5, partly for purposes of expediency, since more is known about the decomposition temperature of hydrazine than is known about fuel-rich combustion of Hydrazine blends. Another reason for selecting N_2H_4 was to take advantage of the most compatible chemical environment for the turbine (reducing atmosphere with no chlorine or fluorine products).

(C) Alternatives for primary combustor operation were to use one of the Hydrazine blends as a monopropellant, or as the fuel in fuel-rich bipropellant operation. These alternatives were not analyzed quantitatively because they would not substantially change the basic engine flows or pressures. It will be seen later in this report that there is sufficient margin for such variations with this particular set of propellants if some blend is eventually used in place of Hydrazine. Still another alternative was to operate the primary combustor oxidizer-rich. This was initially analyzed in the hope that the turbine temperature would be low, but was not pursued after it became evident that the turbine temperature would be approximately 1500°F, which was considered high for turbine materials in a fluorine-rich atmosphere.

(C) Flow schematics of the four analyzed Cases 1 through 4 are shown in Figures III-2 through 5. The advanced-propellant cases, Cases 2, 3, and 4, as well as ARES Case 1, all utilize boost pumps, suction valves, a secondary

C, Cycle Definition (cont.)

control valve, and regenerative cooling tubes in series with the main propellant circuit to the primary combustor. Except for the propellants, the schematic for Case 2 (N_2O_4/Alumizine) is identical to the schematic for Case 1 (ARES N_2O_4/AeroZINE 50). The schematics for Case 3 (H_2O_2/Alumizine) and Case 4 (Compound A/N_2H_4) are similar; they show monopropellant operation of the primary combustor, elimination of the second-stage pump, and relocation of the primary combustor control valve. Cases 3 and 4 differ in that the functions of the fuel and the oxidizer are reversed.

D. HYDRODYNAMIC ANALYSIS

(U) Steady state operating points were established for each case, using the ARES-module power-balance digital-computer Program 102. Sources of propellant and gas properties used in the analysis are referenced in Section I.

(U) To minimize the turbopump power requirements with the advanced propellants and, consequently, to hold down the temperatures and pressures in the system, the pressure drops in the major flow passages and control valves were kept within the ARES pressure schedule (advanced TPA configuration) defined at the time of the study. Figure III-6 shows this pressure schedule.

(C) Consistent with the planned approach, only minimum effort was made to optimize performance parameters in this Phase I study of advanced propellants. To establish flow rates in the engine power balance computations, an approximate specific impulse efficiency (% of theoretical) had to be assumed. In all the propellant cases I_s efficiency was set at 92%, the same as used for the ARES engine. Future development of this value for the different advanced propellants will have little effect on component designs.

(C) Likewise for engine power balance purposes, a nominal coolant flow rate was assumed to be 31 lb/sec for each of the advanced propellant cases.

D, Hydrodynamic Analysis (cont.)

This was the value predicted for the ARES engine at the time. The value would ultimately vary for each propellant case, depending on thrust chamber design and development.

(C) The major assumptions common to each of the cases were:

1.	Thrust at sea level, lb	100,000
2.	Chamber pressure, psia	2,800
3.	Specific impulse, % of theoretical	92
4.	Mixture ratio (SC)	Near optimum
5.	Film-coolant flow, lb/sec	31
6.	Turbopump shaft speed, rpm	40,000
7.	Expansion ratio (A_e/A_t)	20:1

8. Main pump head and flow design points were adjusted to attain ARES efficiencies (advanced TPA).
9. Boost pumps were not redesigned.
10. Turbines were not redesigned, except for adjustment in turbine nozzles areas.
11. Propellant inlet temperature was 77°F. For the advanced propellants, the exit temperature (inlet temperature to primary combustor) of the regenerative coolant was assumed to be 270°F, which is conservatively high.

(U) The following adjustments were made for specific conditions depending on the propellant combinations:

1. Supply lines to boost-pump turbines were increased in diameter where required to maintain pressure and flow to turbines.

2. Suction pressures to the boost pumps were set at 30.4 psia for all the propellants except for Compound A; suction pressure for this propellant was set at 80 psia to compensate for its high vapor pressure.

D, Hydrodynamic Analysis (cont.)

3. Flow resistances in the burnoff seal circuits were adjusted where required to give reasonable mixture ratio and temperature without excessive coolant flows.

(U) The computed results for each case are summarized in Figure III-7. Case 1 shows the operating point of the ARES engine with its current propellants, N_2O_4 and AeroZINE 50.

(C) Case 2 in Figure III-7 shows that operation with N_2O_4 and Alumizine-43 demanded a high turbine gas temperature of approximately 1885°F with the pump-discharge pressures raised to about 6350 psia.

(C) In Case 3, for 98% H_2O_2 and Alumizine-43, the turbine temperature was high at 2047°F, resulting from the predicted 100% decomposition of 98% peroxide preheated to 270°F. In this case, the gas temperature is relatively sensitive to the liquid temperature (1.8°F for each 1°F, respectively) and is penalized by the conservatively high initial assumption of 270°F at the exit of the regenerative coolant tubes. With unheated peroxide, as for instance in transpiration cooling, the turbine temperature would be much lower (1770°F). The pump-discharge pressures also would be reduced by several hundred psi with transpiration cooling; this would apply to the other propellant combinations as well.

(C) In Case 4, for Compound A and N_2H_4, the turbine temperature was approximately 1900°F. This was due to the monopropellant decomposition of the N_2H_4. The temperature was selected midway in the achievable range of catalytic decomposition of N_2H_4, rather than on the low side, to allow for the unknown effect of high pressure (4000 psi). Another reason for selecting the high temperature was to simulate the use of an N_2H_4 blend such as MHF-3 or MHF-5, which would yield a similarly high temperature. The theoretical decomposition temperature of an N_2H_4 blend would necessarily be increased by the elevated

pressures, and also by the addition of oxidizer (Compound A) for fuel-rich bipropellant operation in case the particular blend was not a satisfactory monopropellant. The actual cases of operation with typical N_2H_4 blends were not analyzed quantitatively because it was evident that the pressure levels in the Compound A/N_2H_4 system were sufficiently low to ensure flexibility of operation with any of the N_2H_4 blends.

(U) It should be noted that the boost pumps operated off their design points and demanded excessive bypass flow to drive their turbines because the pumps were not optimized for this study. These flows could be reduced by using boost pumps with different design points. This was not done in the analysis, because the higher flows driving the boost pumps had only minor effects on the main parameters in the module system.

E. HEAT TRANSFER ANALYSIS

1. Objective

(C) The ARES regeneratively cooled secondary combustor-thrust chamber was evaluated to establish its use potential with the advanced propellant combinations N_2O_4/Alumizine-43, H_2O_2/Alumizine-43 and Compound A/N_2H_4 and to establish recommended design changes to the curr[illegible] ARES chamber design to facilitate potential conversion at a later date.

2. Approach

(U) The analytical approach for evaluating the use of the ARES thrust chamber with the advanced propellant combinations was accomplished by comparing the chamber heat load (quantity of heat per unit area transferred from the combustion gases to the chamber wall) and the heat-flux capability (quantity of heat per unit area absorbed and removed by the regenerative coolant).

E, Heat-Transfer Analysis (cont.)

The quantities of heat load and coolant capabilities were compared to those of the ARES design values with N_2O_4/AeroZINE 50. For purposes of comparison, this study was calculated for conditions of no film cooling. In actual development, some film cooling may be required. As mentioned previously in Section D, for engine power balance purposes the film cooling flow rate was assumed to be 31 lb/sec in all cases.

3. Discussion

(C) The heat transfer evaluation was performed for the secondary combustor operating condition as tabulated in Figure III-7. The assumptions and design values used in the heat transfer analysis are tabulated below:

Combustion efficiency, %	100
Contour	
Chamber diameter, in.	10.5
Throat diameter, in.	5.214
Area ratio	20
Coolant Jacket	
Number of passes	2
Number of tubes	104
Tube-wall material	Inconel 718
Tube-wall thickness, in.	0.015
Tube-wall thermal conductivity, Btu/in. sec °F	0.00026
Coating Material	85% W-12% [illegible]-3% Si
Thermal conductivity, Btu/in. sec °F	0.00016
Gas Transport Properties	Based on free-stream temperature

E, Heat-Transfer Analysis (cont.)

(U) A reduction in combustion efficiency from 100%, as assumed in this study, will lower the gas-side heat-flux loads significantly, particularly at the higher surface temperatures.

a. Chamber Heat Load

(U) The chamber heat loads were calculated for N_2O_4/AeroZINE 50 propellant combination and for the three prospective advanced propellants. The analysis was performed for gas-side wall temperatures of 1500°F, which represents a maximum for an uncoated chamber, and for 3500°F, which represents an assumed maximum for a coated chamber. Calculated gas-side heat loads to a 3500°F wall are presented in Figure III-8 from the injector to nozzle exit. These heat loads were evaluated using a gas-side heat-transfer coefficient (hg), as determined from the following equation, where the Dittus-Boelter (DB) number defines the chamber environment.

$$hg = \frac{DB\ \dot{W}g^{.8}}{D_c^{1.8}}$$

where

hg = Gas-side heat transfer coefficient, Btu/in. sec °R

DB = Dittus-Boelter number

$\dot{W}g$ = Mainstream gas flow rate, lb/sec

D_c = Chamber diameter, in.

This coefficient was increased by a factor of 1.5 in the cylindrical section to account for turbulence in the combustion zone. The factor was decreased linearly with area ratio to 1.0 at the throat.

E, Heat-Transfer Analysis (cont.)

b. Regenerative Coolant Tube Heat Flux Capability

(U) The heat fluxes of the regenerative coolant tubes were evaluated using the oxidizer as the coolant for all of the propellant combinations except for Compound-A/N_2H_4 where N_2H_4 was evaluated. Figure III-9 shows the calculated liquid-side flux capability of the tubes from the injector to the nozzle exit, with the ARES tube design considered for each of the propellants. It is noteworthy that use of the ARES tube design results in throat coolant velocities near 100 ft/sec with the advanced propellants, whereas the ARES regenerative coolant (N_2O_4) reaches 200 ft/sec at the throat.

c. Gas-Side Heat Load Versus Regenerative Coolant Capability

(U) The secondary combustor will operate satisfactorily only if the heat-flux capability of the regenerative coolant tubes is greater than the gas-side heat load. Figure III-10 is a plot of gas-side heat load versus liquid-side coolant capability at the throat. The liquid-side coolant capability for the advanced propellants is shown for the two-pass ARES regenerative coolant tubes and for a modified two-pass coolant-tube system with increased velocity utilizing the allocated pressure drop of the ARES pressure schedule. Tube-wall thickness for both the ARES and the modified ARES engine is 0.015 in. Analysis indicated that increasing the velocities to the limit of the allocated ΔP increased the coolant flux capability only slightly. However, the higher coolant velocity will greatly increase the burnout heat flux. This could justify an increased coolant flow velocity. Figure III-10 shows that in all cases the heat load is greater than the cooling capability, with the heat load for the metallized propellant combinations being about twice that for the nonmetallized propellant combinations. From Figure III-10 it can also be concluded that satisfactory operation can only be achieved by adjusting the heat-load balance so that the cooling capability is greater than the net

heat load. This can be achieved by various methods, such as: (1) film-cooling to reduce gas-side boundary temperatures and transport properties, (2) higher gas-side wall temperatures to reduce heat load, (3) lower tube wall thickness, lower barrier thickness, and increased liquid heat-transfer coefficient (h_L) to increase liquid-side cooling capability, (4) alternative cooling concepts such as ablative, liquid-transpiration, or gas-transpiration.

4. Conclusions

(U) The ability to operate the secondary combustor with the prospective advanced propellants will require adjusting the relationship between heat load and cooling capability so that the cooling capability is greater than the heat load. It is beyond the scope of this study to evaluate the capability and merits of prospective cooling concepts except to define the adaptability of the engine to such concepts. Since cooling concepts other than regenerative cooling, with and without coating, were not yet sufficiently developed at the time of this analysis, evaluation of convertibility to a specific cooling concept will remain to be defined in Phase II of this advanced-propellant study.

F. MATERIAL EVALUATION

(U) The materials selected for use in each component of the ARES module were evaluated for future compatibility in advanced-propellant applications.

(U) The ARES material list, shown in Figure III-11, is identical to that published in the first quarterly report. It includes a list of ARES materials and the materials recommended for improved compatibility with advanced propellants. Both the current materials and the recommended materials are preliminary selections because neither the design nor the stress

F, Material Evaluation (cont.)

analyses of components to be made from these materials have been completed. However, since the advanced-propellant analysis was completed, several of the materials recommended for use with advanced propellants have been incorporated into the designs of such ARES components as the hydrostatic fuel seal and the labyrinth seals.

G. ENGINE COMPONENT SIZING

(U) The approach for establishing the changes required to the ARES module design to permit operation with the three prospective sets of advanced propellants consisted of (1) establishing the optimum dimensions required for the operating point tabulated in Figure III-7, (2) comparing these values with the ARES design values, and (3) defining the adequacy of the ARES components for advanced-propellant application. To facilitate this evaluation, the ARES cycle and the cycle using the advanced propellants are defined in terms of propellant circuits, i.e., primary combustor propellant supply system, etc. The calculated design point flow-passage dimensions for the operating point of Figure III-7 are tabulated in Figure III-12 for each propellant circuit. These dimensions were based on the basic ARES pressure schedule in Figure III-6. Similarly, the calculated component dimensions are presented in Figure III-13 for the noted operating points.

(U) The objective of this study was to establish the mandatory changes required to achieve satisfactory, but not necessarily optimum operation with the advanced propellants. These changes are discussed in the following paragraphs.

Advanced Propellants (cont.)

H. RECOMMENDED CHANGE

1. General

(U) The recommended changes to the basic ARES module design were obtained from the dimensional, material, and heat-transfer studies discussed in paragraphs E, F, and G, above. From these studies, it was possible to identify the adequacy of the module's components, identify the action required to make a specific component adequate, and establish a recommended timing for this action. The ground rules for defining the required action and their timing relative to the program were:

a. Achieve a thrust level of 100,000 lb with the basic ARES engine.

b. Achieve convertibility of the advanced module design as shown in Figure III-1.

c. Permit ± 25% off-design flow operation of ARES components.

d. Permit system pressure drops to 110% of values specified in the ARES pressure schedule.

e. Rework ARES components to achieve power balance.

f. Recommend design changes for the ARES Phase-I effort only if this will enhance future convertibility without compromising the basic ARES design objective.

H, Recommended Change (cont.)

2. Recommended Changes

a. Dimensional

(U) The nominal dimension for flow passages and components of the basic ARES module for the N_2O_4/AeroZINE 50 and the three advanced-propellant combinations are presented in Figures III-12 and III-13. The tabulated values of component and flow-passage dimensions for advanced propellant operation were compared to the dimensions tabulated for ARES module operation with N_2O_4/AeroZINE 50. The adequacy of the ARES dimensional values for each of the advanced-propellant applications is listed in Figure III-14. The recommended action to achieve satisfactory operation for components identified as being adequate is also defined as well as the recommended timing for this action.

(C) It can be seen that the application of advanced propellants to the ARES N_2O_4/AeroZINE 50 cycle introduces the requirement to (1) reduce the volume flow-rate in the propellant circuit of the primary combustor by a factor of approximately 2, (2) increase the volume flow-rate in the liquid-propellant circuit of the secondary combustor by a factor of approximately 2. It can also be seen that propellant passages will be adequate if current dimensions are larger than those required for advanced propellants.

(C) The ARES components that are adequate for conversion without change are the primary combustor bipropellant fuel valve (Case 2), the boost pumps, the suction lines, and the suction valves. The ARES turbopump main oxidizer housing is satisfactory as presently designed with the two metalized propellants. It can be made satisfactory for Compound-A/N_2H_4 by operating at a shaft speed greater than the specified 40,000 rpm, by reducing the operating pressure of the secondary combustor, or by changing the housing

H, Recommended Change (cont.)

to accept an impeller of 5.37-in. dia. The Compound A/N_2H_4 design uses a 5.37-in.-dia impeller to pump the N_2H_4 into the ARES turbopump main housing.

(U) The oxidizer impeller can be reworked for use with Alumizine-43 (Cases 2 and 3). The fuel second-stage impeller can be reworked for bipropellant operation.

(U) The remainder of the ARES module components will have to be resized to achieve satisfactory operation with advanced propellants.

b. Materials

(U) The original ARES materials and the materials recommended for use with advanced propellants are shown in Figure III-11. It can be seen that all ARES components that have been shown to be dimensionally adequate are also adequate if made from ARES materials. This includes the primary combustor bipropellant fuel valve, boost pumps, suction lines, and suction valves. The material in the turbopump main housing is also satisfactory for the three prospective advanced propellants. The ARES components which can be made adequate dimensionally by reworking are also satisfactory from material considerations. These reworkable components include the ARES N_2O_4 impeller and the ARES second-stage fuel impeller. The balance of the components, which would have to be redesigned for dimensional compatibility, should be made from materials recommended in Figure III-11. Miscellaneous components such as seals, labyrinth, liners, etc., have not been reviewed for dimensional adequacy, but recommended materials should be reviewed for applicability in the basic ARES designs.

H, Recommended Change (cont.)

c. Heat Transfer

(U) Results of the thrust-chamber (secondary combustor) heat-transfer analysis indicated that a satisfactory cooling concept still requires feasibility demonstration. Since there are no specific advanced-propellant thrust-chamber designs to which the ARES chamber can be compared, no recommendations can be made. The turbopump main housing with its interface to a 10.5-in.-dia secondary combustor appears to be sufficiently adaptable to prospective cooling concepts.

d. ARES Oxidizer-Rich Primary Combustor

(U) The studies conducted in Phase I have clearly shown that the relative fluid-flow decrease in the primary combustor and the relative increase in the secondary combustor precluded the use of many ARES components with advanced propellants. The convertibility of the ARES module could be increased if the relative propellant flow values were similar for all propellant considerations. This could be achieved if the basic ARES engine using N_2O_4/AeroZINE 50 propellants were to operate with a fuel-rich primary combustor in lieu of the oxidizer-rich primary combustor. The resulting low flows in the primary combustor circuit and high flows in the secondary combustor liquid-propellant supply circuit would permit the direct use of all passages with the three advanced-propellant combinations. The pump on the primary combustor supply circuit would be pumping AeroZINE 50, which would result in a pump-diameter envelope that would meet or exceed the envelope required for any of the three prospective advanced propellants.

(C) It was also observed that if the ARES engine were designed with a fuel-rich primary combustor, some of the feasibility and development problems predicted for the advanced propellants would first have

H, Recommended Change (cont.)

to be solved in the ARES program. These problems include turbine operation at temperatures of up to 2000°F and the development of a fuel-rich primary combustor and new secondary combustor.

(U) It is not recommended at this time that the ARES cycle be changed from oxidizer-rich to fuel-rich primary combustor operation to facilitate conversion of the N_2O_4/AeroZINE 50 ARES engine to operation with advanced propellants. Such a change would introduce new development problems beyond the scope of the present program.

(U) The objective of the ARES Phase-II advanced-propellant program will be to prepare design specifications and a conceptual engine design. This design will be based on the final ARES Phase-I module design, on the results of this study effort and on optimized engine internal-flow and pressure values. These optimized values will include results of secondary combustor mixture-ratio optimization studies that were initiated for 98% H_2O_2/Alumizine under the Advanced Propellant Program, Contract AF 04(611)-10785.

I. PROPELLANT AND GAS PROPERTIES

(U) The following sources of propellant properties were used in the advanced-propellant study:

OXIDIZERS

N_2O_4

Density, heat capacity, viscosity, thermal conductivity, vapor pressure:

ARES Engine Handbook (U), Aerojet-General Report 10830-EHB, Rev. 2 (Confidential), 27 August 1965, Contract AF 04(611)-10830.

I, Propellant and Gas Properties (cont.)

H_2O_2

Density, heat capacity, viscosity, thermal conductivity:

Advanced Propellant Staged Combustion Feasibility Program (U), Aerojet-General Report 10785-Q-1 (Confidential), 15 September 1965, Contract AF 04(611)-10785.

Vapor pressure:

Scatchard, Kavanagh, Titcknor, Journal American Chemical Society, 74, 3715 (1952).

Compound A

Density:

Applied Research Program to Evaluate the Feasibility of the Compound A/Hydrazine Propellant System (U), Rocketdyne Report R-5619-1, Part I, Contract AF 04(611)-9573 (Confidential), March 1964.

Vapor pressure:

Preparation and Characterization of a New High Energy Oxidizer (U), Rocketdyne Peport R-5599-3, AF 04(611)-9563 (Confidential), September 1964.

I, Propellant and Gas Properties (cont.)

FUELS

AeroZINE 50

Density, vapor pressure:

ARES Engine Handbook (U), Aerojet-General Report 10830-EHB, Rev. 2 (Confidential), 27 August 1965, Contract AF 04(611)-10830.

Alumizine 43

Density:

Computed from aluminum and hydrazine,

$$\text{Density of Alumizine 43} = \frac{1}{\left(\frac{\text{Mass Fraction}}{\text{Density}}\right)_{\text{Alum}} + \left(\frac{\text{Mass Fraction}}{\text{Density}}\right)_{N_2H_4}}$$

$$\text{At } 77^{\circ}\text{F, Density} = \frac{1}{\left(\frac{.43}{169}\right) + \left(\frac{.57}{62.7}\right)} = 85.9$$

Vapor pressure: Same as hydrazine; see below.

Hydrazine (N_2H_4)

Density, heat capacity, viscosity, thermal conductivity:

Performance and Properties of N_2O_4/AeroZINE 50 and Selected Metallized Storables (U), Aerojet-General Report LRP302 (Confidential), March 1963, Contract AF 04(611)-8191.

I, Propellant and Gas Properties (cont.)

Vapor pressure:

Scott, D. W., et al, Journal American Chemical Society, 71, 2293-2297 (1949).

GAS PROPERTIES

The following sources of gas properties were used for all the propellant combinations:

Primary Combustor Gas

Temperature, heat capacity, molecular weight, reaction products:

Aerojet-General Corporation Theoretical Chemical Composition and Propellant Performance Computer Program 166.

Secondary Combustor Gas

Specific impulse, characteristic velocity, temperature, combustion products:

Aerojet-General Corporation Theoretical Chemical Composition and Propellant Performance Computer Program 166.

Dittus-Boelter Coefficient:

Aerojet-General Corporation Propellant Combustion Products Properties Computer Program 287D.

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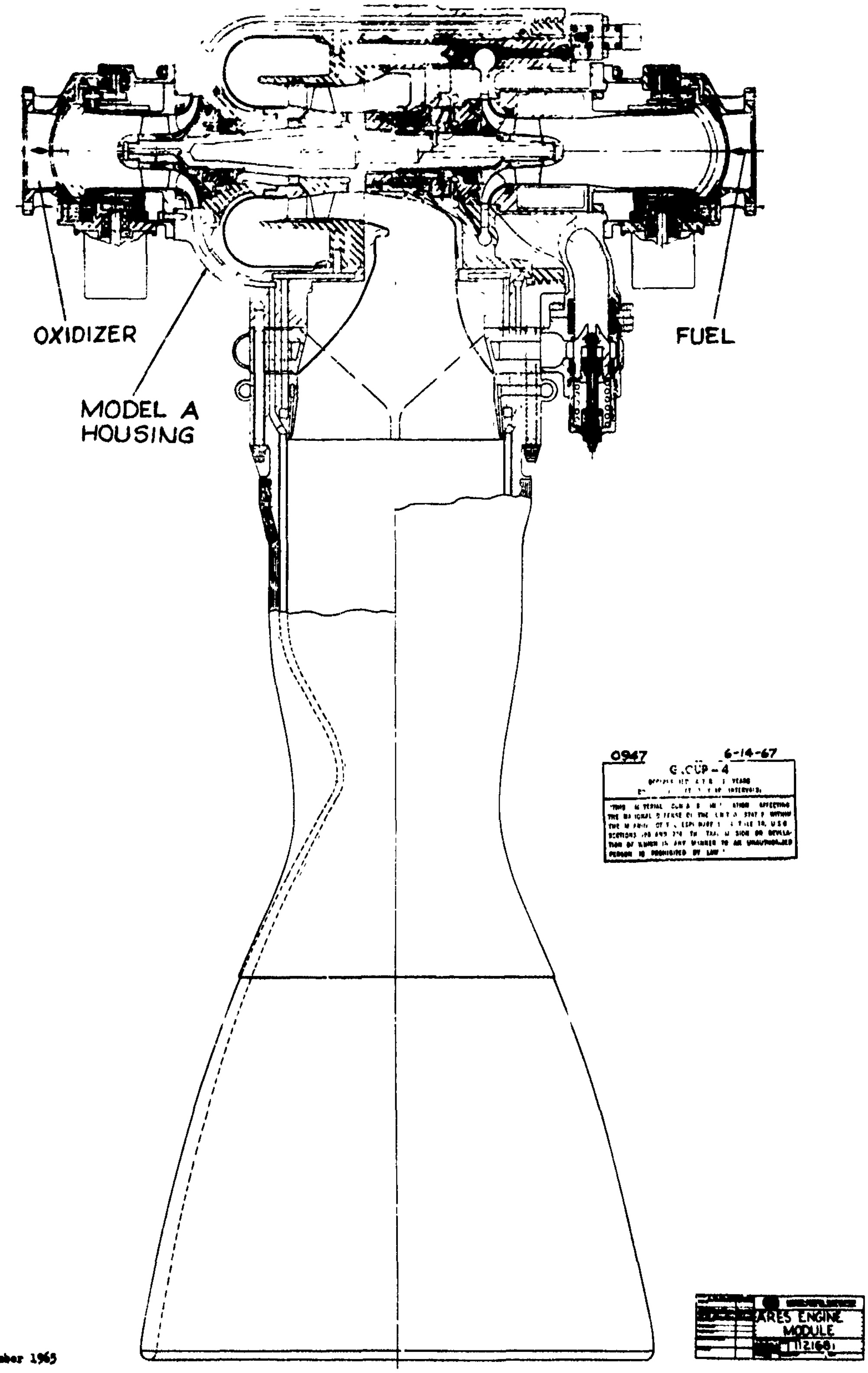

28 September 1965

ARES Engine Module (u)

Figure III-1

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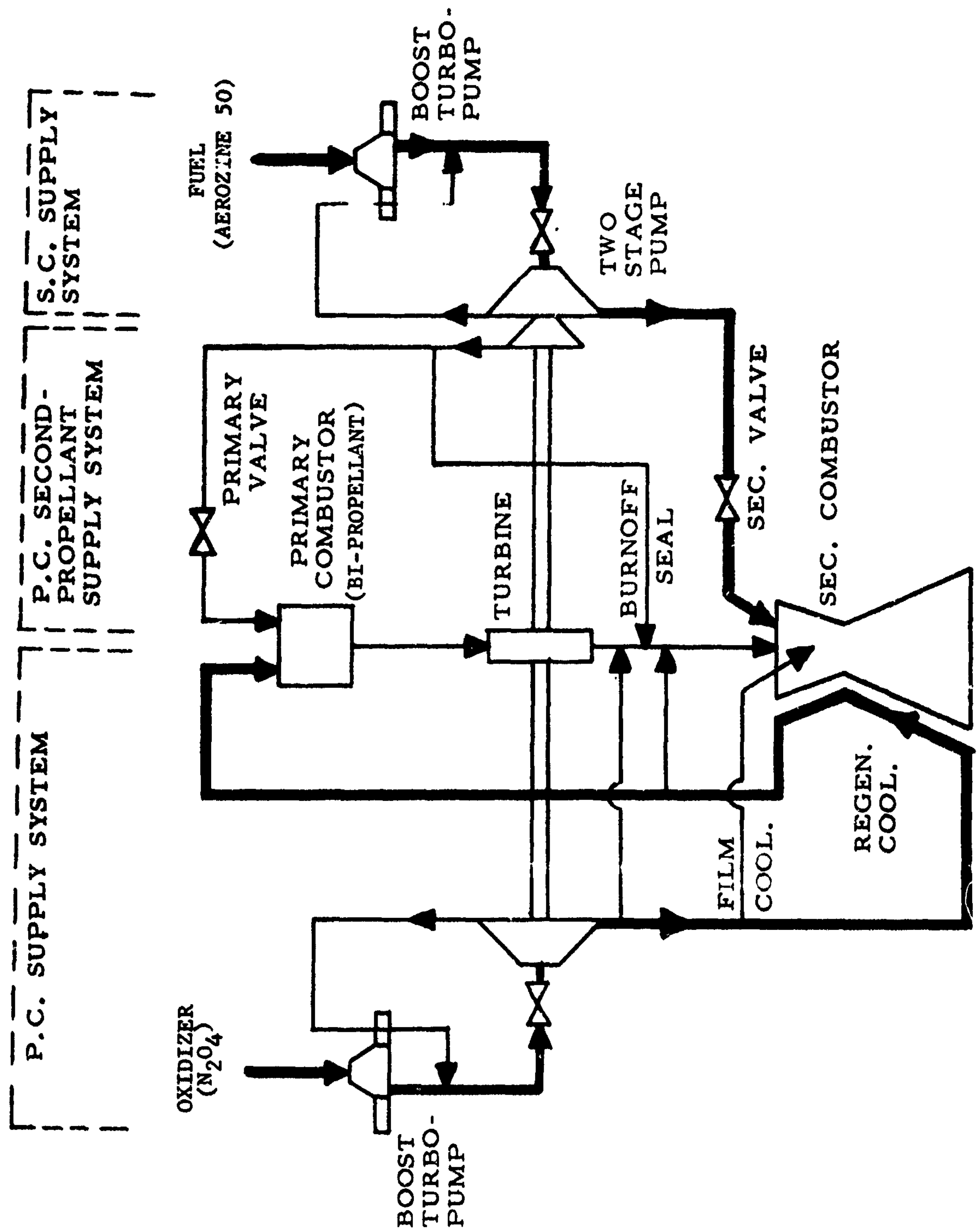
PROPELLANT CYCLE: Prim. Comb. Operation	PROPELLANT CYCLE: Sec. Comb. Coolant	N_2O_4 AeroZINE 50*	N_2O_4 Alumizine 43	98% H_2O_2 Alumizine 43	Comp. A N_2H_4
Bipropellant, Oxidizer Rich	Oxid. Cool	Case 1 (ARFS)	Case 2		
	Fuel Cool				
Bipropellant, Fuel Rich	Oxid. Cool				Recommended for some N_2H_4 Blends but not analyzed separately. See Case 4.
	Fuel Cool				
Monopropellant Oxidizer	Oxid. Cool			Case 3	
	Fuel Cool				
Monopropellant Fuel	Oxid. Cool				
	Fuel Cool				Case 4

*AeroZINE 50 - Aerojet-General Corporation Trade Name for 50% UDMH and 50% N_2H_4 fuel blend.

Advanced Propellant--Cycle Candidates

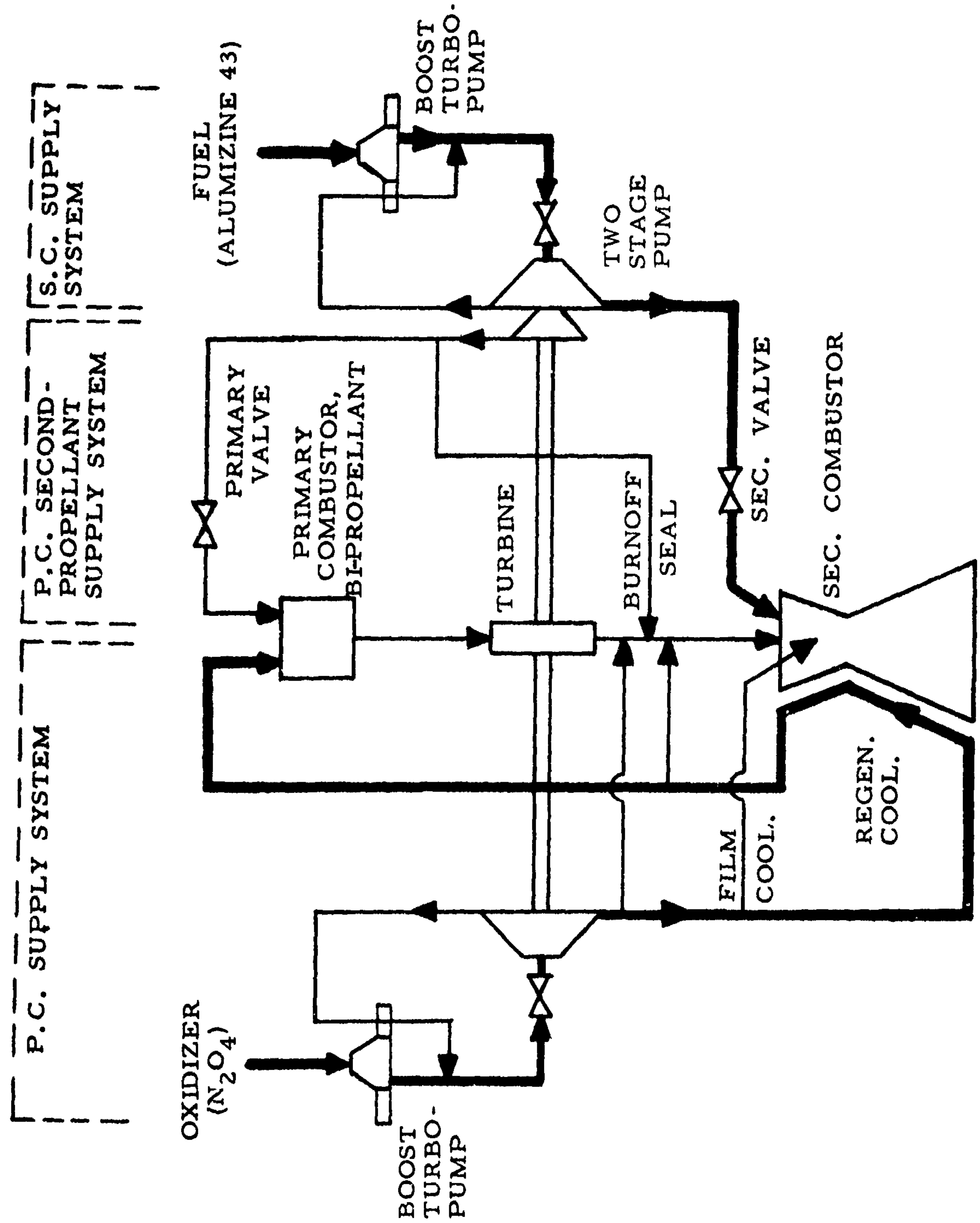
(This page is Unclassified)

Figure III-1a



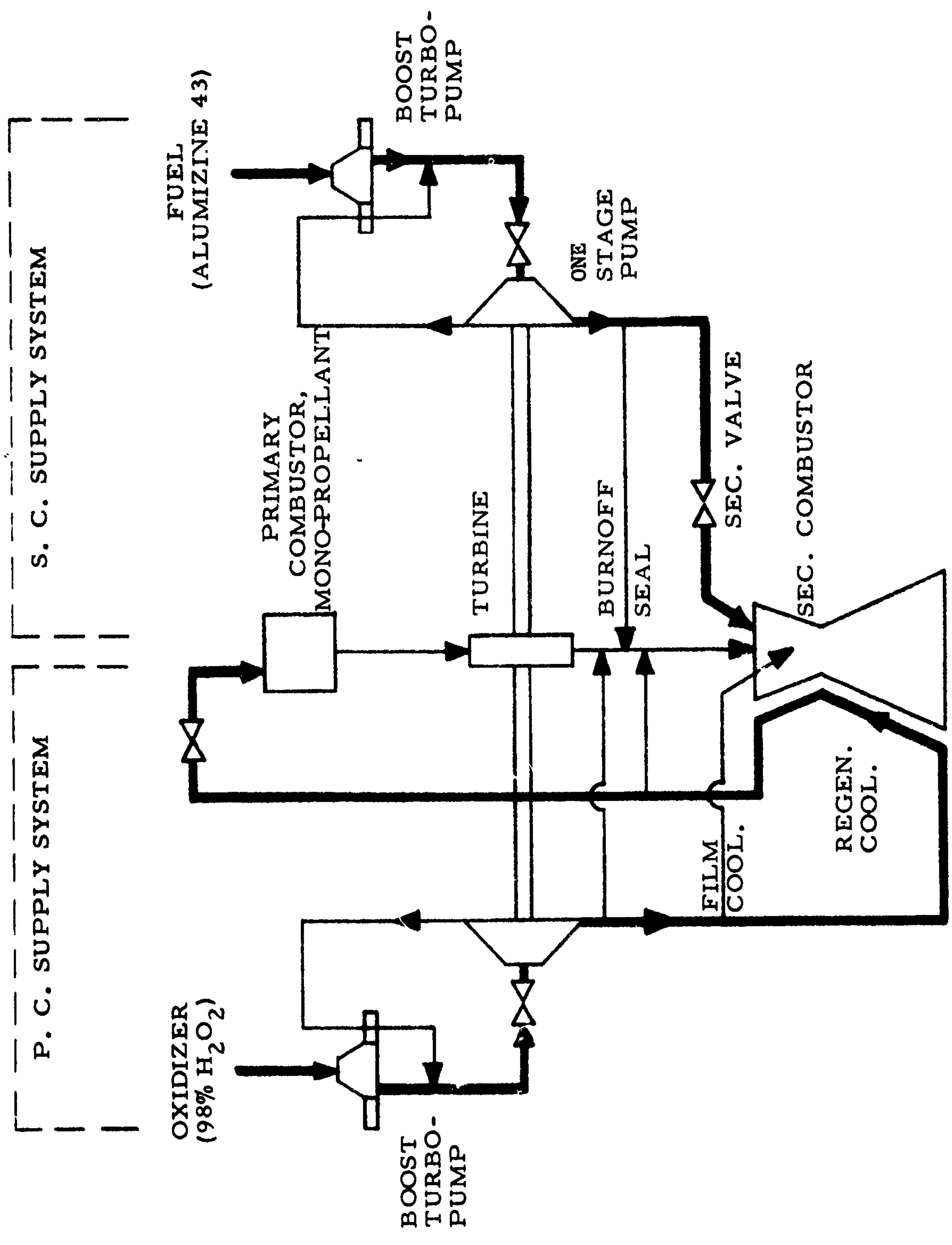
Flow Schematic Case No. 1 N_2O_4/AeroZINE 50 (u)

Figure III-2



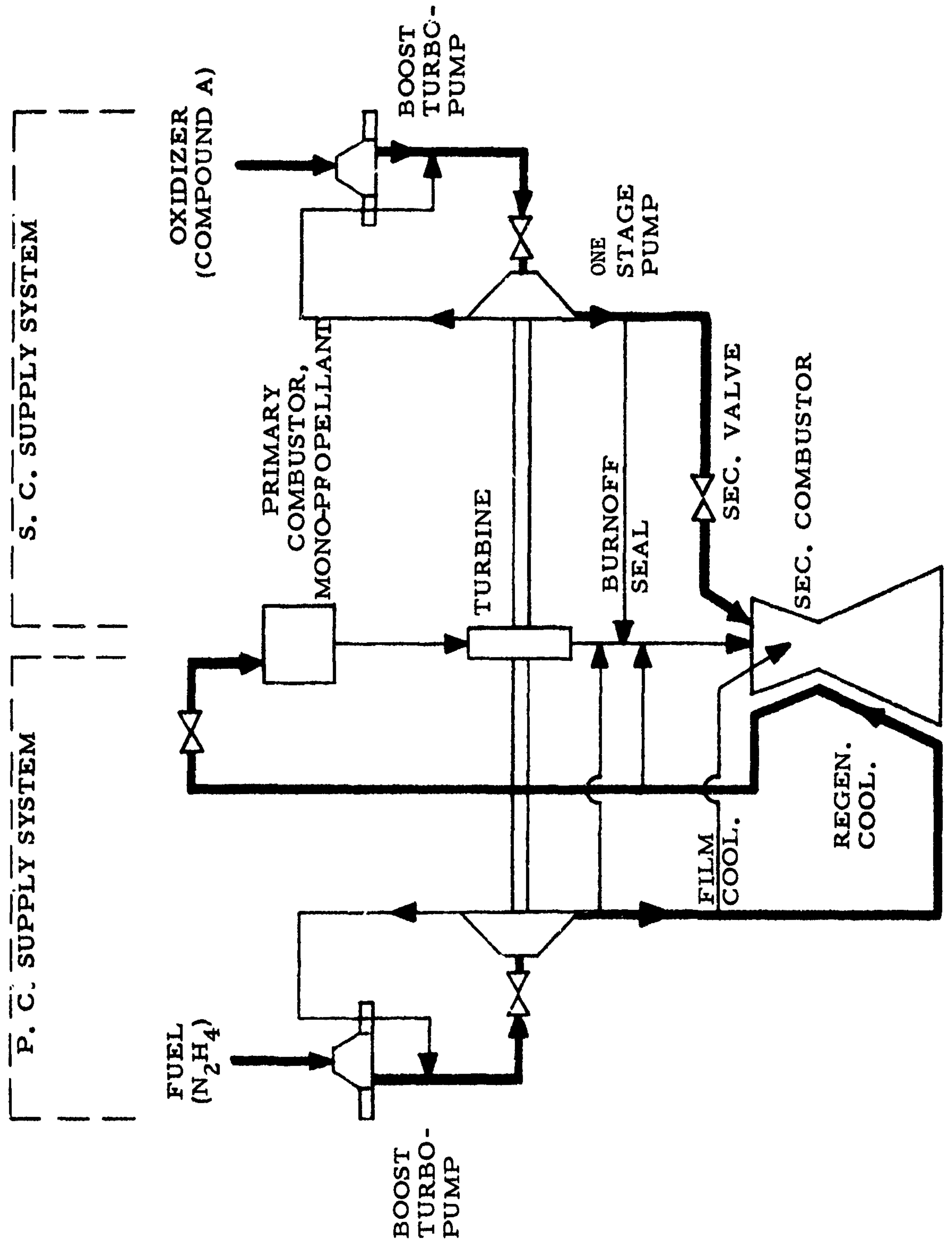
Flow Schematic Case No. 2 N_2O_4/Alumizine 43 (u)

Figure III-3



Flow Schematic Case No. 3 98% H_2O_2/Alumizine 43 (u)

Figure III-4



Flow Schematic Case No. 4 Compound A/Hydrazine (u)

Figure III-5

	Film Cool. (Oxidizer)	Primary Combustor Turbine Circuit (Oxidizer)	Primary Combustor Turbine Circuit (Fuel)	Secondary Combustor (Fuel)
Boost Pump Inlet (psia)	30.4(NPSH=20 ft)			10.6(NPSH=20 ft)
Boost Pump Discharge	309			167
Line and Valve ΔP (psi)	55			36
Main Pump Inlet	254 (NPSH=379 ft)			131 (NPSH=330 ft)
Main Pump Discharge	6200			3750
2nd Stage Fuel Pump Inlet				3600
2nd Stage Fuel Pump Discharge				5739
Manifold ΔP	125	125	100	100
Cooling Jacket ΔP		775		
Cooling Jacket Exit		5300		
Manifold ΔP		100		
Control Valve ΔP		125	464	350
Balancing Orifice ΔP	725			
PC Injector Inlet		5075	5175	
PC Injector ΔP		300	400	
PC Injector Face		4775		
Δ P to Turbine Inlet		125		
Turbine Inlet		4650		
Turbine Δ P		1550		
Turbine Pressure Ratio		1.50		
Turbine Exit		3100		
Δ P to SC Injector	50	115		100
SC Injector Inlet		2985		3200
SC Injector ΔP		100		315
Film Cooling ΔP	2500			
SC Injector Face		2885		
Δ P to SC Plenum		85		
SC Chamber Pressure Ratio		1.03		
SC Chamber Pressure (P_c)		2800		

27 August 1965

ARES Pressure Schedule (u)

Figure III-6

Parameter	Units	Case 1 Oxid/Fuel	Case 2 Oxid/Fuel	Case 3 Oxid/Fuel	Case 4 Oxid/Fuel
PROPELLANTS		N_2O_4/A-50	N_2O_4/Al 43	98% H_2O_2/Al 43	COMP. A/N_2H_4
Density at 77°F	lb/ft^3	89.5/56.1	89.5/85.9	89.33/85.9	108.3/62.7
Vapor Pressure at 77°	lb/ft^3	18.0/2.8	18.0/0.3	0.04/0.3	56/0.3
MODULE ASSEMBLY					
Thrust, F	lb	100,000	100,000	100,000	100,000
Is (Sea Level, 92% Theor.)	sec	285	300.3	304.4	309.7
Mix. Ratio, Engine, MR		2.51	0.762	0.656	1.94
Total Weight Flow, $\dot{W}_T$	lb/sec	350.9	333	328.6	322.8
Weight Flows, $\dot{W}_O$, $\dot{W}_F$	lb/sec	250.9/100	144/189	130.2/198.4	213/109.8
Suction Press. P_{OS}, P_{FS}	psia	30.4/10.6	30.4/30.4	30.4/30.4	80/30.4
SECONDARY COMBUSTOR					
Chamber Press. Plenum, P_c	psia	2800	2800	2800	2800
Mix. Ratio, Inj MR_{SC}		2.20	0.60	0.50	2.7
Regen. Cooling Flow, $\dot{W}_{RG}$	lb/sec	219.9/-	110/-	96/-	-/78
Film Cooling Flow, $\dot{W}_{FC}$	lb/sec	31/-	31/-	31/-	-/31
Injector Flow	lb/sec	239.9 /80.0 (gas)	158.5/174.5 (gas)	130.8/197.8 (gas)	212.5/110.3 (gas)
Area Ratio, A_e/A_t	20	20	20	20	20
ΔP Regen. Cool. Tube	psi	775/-	775/-	775/-	-/775
Char. Velocity, C^*_{SC}	ft/sec	5443	5629	5693	6083
PRIMARY COMBUSTOR					
Chamber Press., P_{PC}	psia	4775	5095	4609	4156
Mix. Ratio, MR_{PC}		11.2	7.85	-	-
Flows, $\dot{W}_{OPC}$, $\dot{W}_{FPC}$	lb/sec	213.1/19.0	103.9/13.2	90/-	-/76
TURBINE, MAIN					
Gas Flow, $\dot{W}_{Ti}$	lb/sec	232.1	117.1	90	76
Gas Temp., T_{tit}	°F	1252	1885	2047*	1900
Press. Turb. Inlet, P_{tit}	psia	4650	4960	4490	4050

*Assumes max. preheat with regen. cooling. Would be 1770°F with transpiration cooling.

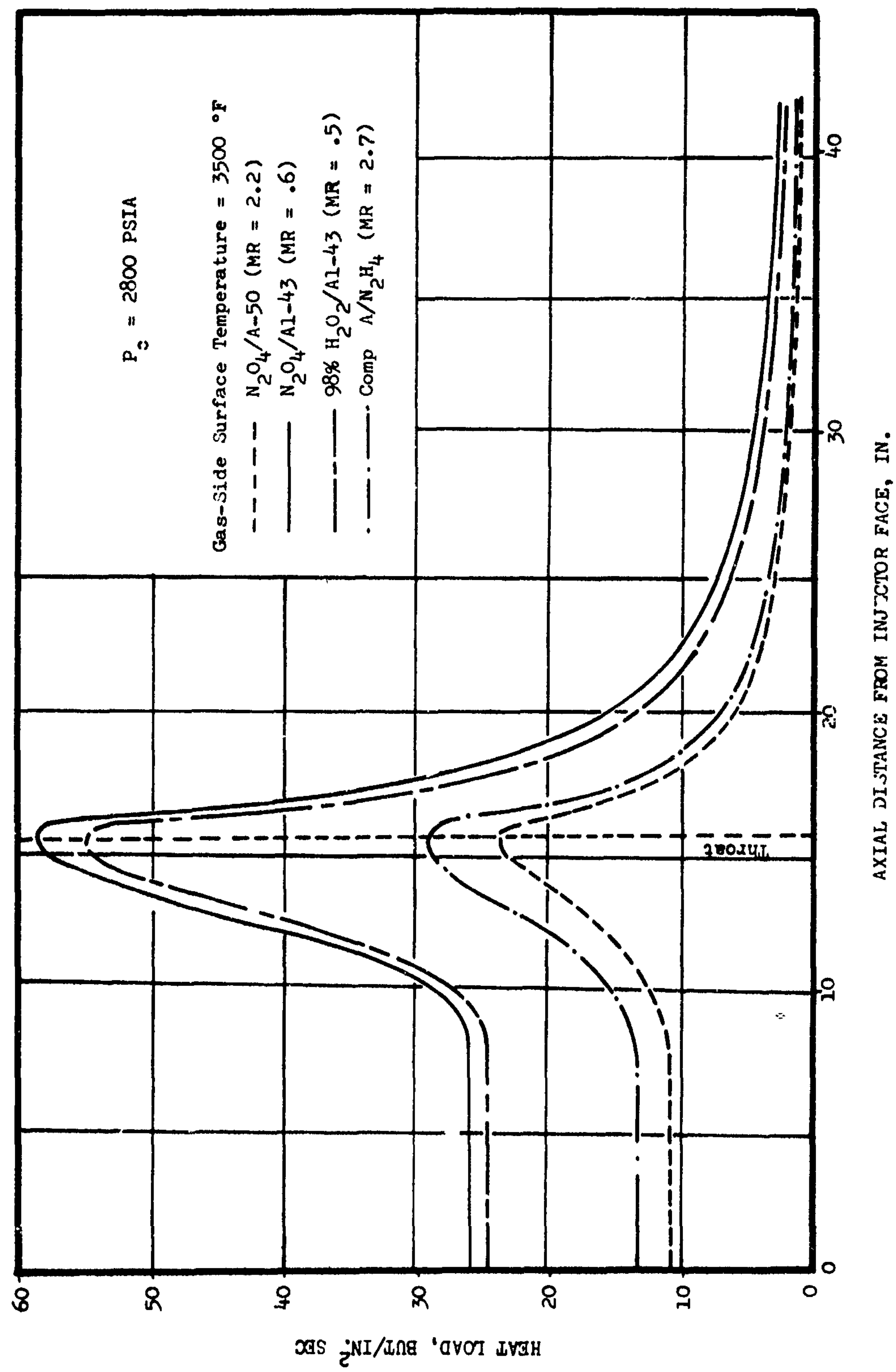
Module Operating Parameters--Advanced Propellants (u)

Figure III-7, Sheet 1 of 2

Parameter	Units	Case 1 Oxid/Fuel	Case 2 Oxid/Fuel	Case 3 Oxid/Fuel	Case 4 Oxid/Fuel
Press. Ratio Turb., R_{pt}		1.50	1.60	1.45	1.31
Shaft Power, SHP_t	hp	10,118	7955	7175	6785
Efficiency, Turb. η_t	%	76.9	74	71.5	69
Shaft Speed, N_t	rpm	40,072	40,000	40,000	40,000
PUMPS, MAIN					
Suction Press., P_{SM-1}	psia	251/131	251/197	233/197	338/144
Discharge 1st Stg., P_{DM-1}	psia	6200/3750	6350/3750	5800/3750	3750/5320
Discharg[illegible]d Stg., P_{DM-2}	psia	-/5750	- /6000	-/-	-/-
Head, H_{DM-1}	ft	9572/9288	9830/5950	8980/5950	4540/11900
Head, H_{DM-2}	ft	- /5519	-/4020	-/-	-/-
Weight Flow, W_{SM-1}	lb/sec	289.7/115.3	165/239	149.6/250.7	121.1/276.3
Weight Flow, W_{SM-2}	lb/sec	-/22.2	-/15	-/-	-/-
Vol. Flow, Q_{SM-1}	gpm	1467/940	841/1259	765/1310	11[illegible]5/867
Vol. Flow, Q_{SM-2}	gpm	-/178	-/87	-/-	-/-
Efficiency, η_{M-1}	%	73.2/71.6	73/72	73/72	73/72
Efficiency, η_{M-2}	%	-/56.6	-/57	-/-	-/-
Shaft Power, SHP_{M-1}	hp	6953/2771	4100/3625	3400/3770	3150/3635
Shaft Power, SHP_{M-2}	hp	-/394	-/233	-/-	-/-
BOOST PUMPS					
Shaft Speed, N_{TBP}	rpm	7994/7877	6450/8915	6100/9220	6795/7435
Disch. Press., P_{DBP}	psia	307/167	269/294	248/302	380/178
Head, H_{DBP}	ft	445/401	385/443	352/457	400/340
Vol. Flow, Q_{SBP}	gpm	1258/800	722/987	654/1037	883/786
Efficiency, η_{BP}	%	63.8/64.5	57/64	55/63	62/65
Shaft Power, SHP_{BP}	hp	318/113	177/239	350/456	248/104
BOOST TURBINES					
Press. Inlet, P_{t1tBP}	psia	5798/3433	6230/3530	5700/3675	3710/5180
Flow, Turb. W_{TBP}	lb/sec	38.8/15.3	21/50	19.4/52.3	63.3/11.3
Efficiency, η_{TBP}	%	51.0/48.4	49/49	48/49	49/44

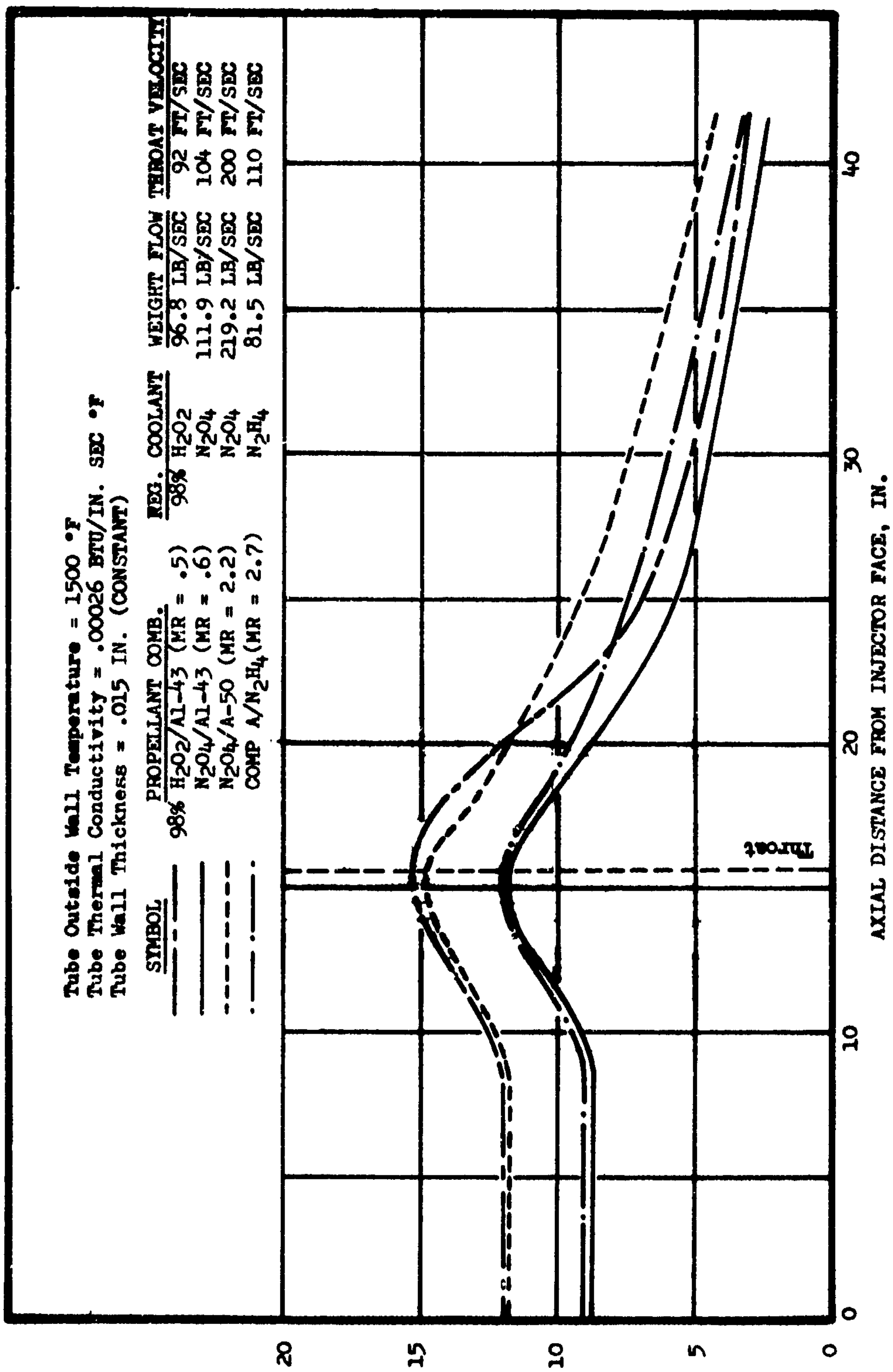
Module Operating Parameters--Advanced Propellants (u)

Figure III-7, Sheet 2 of 2



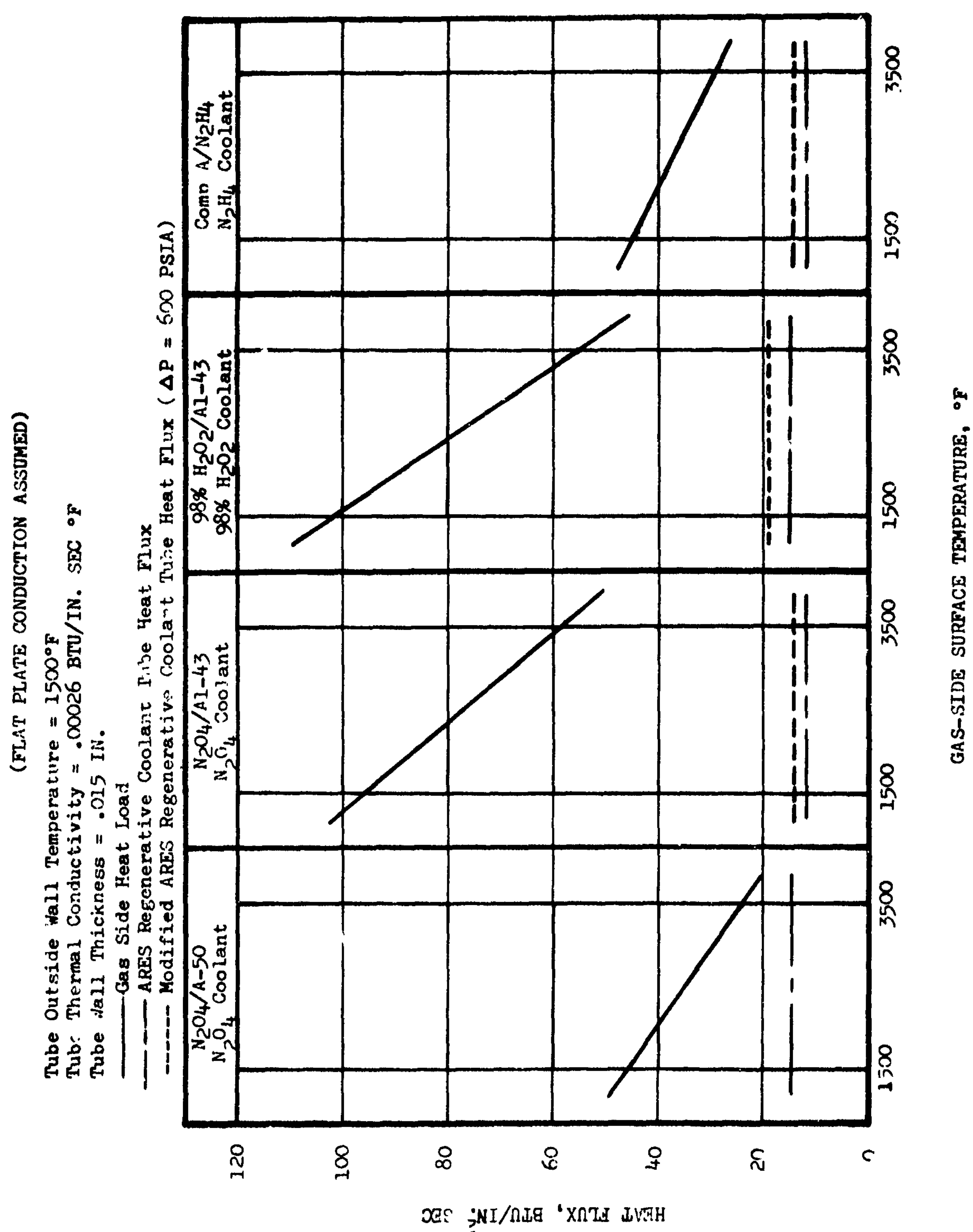
ARES Chamber Heat Load--Advanced Propellants (u)

Figure III-8



ARES Regenerative Tube Heat Flux Capability--Advanced Propellants (u)

Figure III-9



Throat Gas Side Heat Load vs Regen Coolant Capability--Advanced Propellants (u)

Figure III-10

ARES Parts		Recommended Changes for Compatibility with Advanced Propellants	
Part	Material*	Material	Criterion
All pump housings & impellers	INCO 718, SS 347, Al A-356, Ti 6-4, Al 7079	No change	All propellants
Boost pump shafts	AM 350	" "	" "
Main shaft	AM 350	INCO 718	1500°F
Hydrostatic Fuel Seal	Invar, LW-1 Flame Plate	LC-1B Flame Plate	Max wear & corrosion resistance
Turbine Rotor & Nozzle	IN-100	No Change	1900°F
Turb.Rotor Retainer	AM-350	INCO 718	Same material as shaft
Turb. Wear Ring	INCOX-750	Hast X	1900°F
Labyrinth Seals	Carbon	Impregnated teflon	Wear & corrosion resistance, all propellants
Bearings	SS 440C	Demonstration required for compatibility with Al 43 and Comp A	
Bearing Retainers	INCO 718	No change	All propellants
Suction Valves	SS-347, SS-440C, SS-AM 350, Teflon, Kynar	No change " " Teflon only	" " " " " "
Primary & Secondary Fuel Valves	AM-350, 17-7 PH, 440C, Teflon, AS 4004(Butyl)	No change " "	All propellants " "
Suction Lines	Braid, S.S. Lining, Teflon(preliminary)	No change	" "
Primary Injector (& Turb. Housing)	INCO 718, N-155	Hast X	1900°F
Primary Combustor	Hast X	No change	1900°F
Secondary Injector	SS347, N-155	Hast X	1700°F
S.C. Regen Tubes	INCO 718	No change	1500°F
S.C. Coating	Tungsten, Zir.ox., Silicon(Surface not selected)	None selected at this time for above 3500°F	H_2O_2/Al43 4000°F oxid film cool. 4500 no film cool. N_2O_4/Al43 4500 oxid film cool. 5000 no film cool Comp.A/N_2H_4 4000 fuel film cool. 4500 no film cool
Transpiration Cooling	Ni 270	Ni 270 for H_2O_2 or Comp A Hast X for N_2O_4	1500-2000°F with low stress

*ARES material list as of September 1965, the time of the study.

Material Compatibility--Advanced Propellants

(This page is Unclassified)

Figure III-11

Flow Passage	Case 1 N204/A-50 Flow lb/sec	Case 1 *Area in.^{2}	Case 2 N204/AL-43 Flow lb/sec	Case 2 *Area in.^{2}	Case 3 98% H202/AL-43 Flow lb/sec	Case 3 *Area in.^{2}	Case 4 Comp. A/N2H4 Flow lb/sec	Case 4 *Area in.^{2}	ARES Allocated Pressure Drop
PC MAIN PROPELLANT	Oxid		Oxid		Oxid		Fuel		
Suction Line and Valve	290	(K_W) 32.5	165	(K_W) 18.6	150	(K_W) 17.0	121	(K_W) 16.3	ΔP=55 psi
Main Housing & Manifold	248	7.5	141	4.2	127	3.9	109	4.0	ΔP=125
Cooling Jacket (Regen.)	217	(K_W) 6.5	110	(K_W) 3.0	96	(K_W) 2.9	78	(K_W) 2.8	ΔP=775
Manifold to PC	213	6.6	104	3.3	90	2.8	76	2.9	ΔP=100
PC Control Valve (or Orifice)	213	(K_W) 16.1	104	(K_W) 8.1	90	(K_W) 6.9	76	(K_W) 7.0	ΔP=125
PC Injector	213	4.1	104	2.0	90	1.7	76	1.8	ΔP=300
PC SECOND PROPELLANT (BIPROPELLANT ONLY)	Fuel		Fuel						
Second Stage Pump Volute	19	0.17	13	0.10	-	-	-	-	-
Passage to PC Control Valve	19	0.42	13	0.24	-	-	-	-	ΔP=100
PC Control Valve	19	(K_W) 0.92	13	0.52	-	-	-	-	ΔP=464
PC Manifold	19	0.79	13	0.45	-	-	-	-	ΔP= 50
PC Injector	19	0.26	13	0.15	-	-	-	-	ΔP=400
SC LIQUID PROPELLANT	Fuel		Fuel		Fuel		Oxid		
Suction Line & Valve	115	(K_W) 20.3	239	(K_W) 34.0	251	(KW) 35.6	276	(K_W) 35.0	ΔP=36 psi
1st Stage Pump Volute	80	1.6	175	2.8	198	3.2	213	3.0	-
Line to SC Control Valve	80	2.4	175	4.3	198	4.8	213	4.6	ΔP=100
SC Control Valve	80	(K_W) 4.5	175	(K_W) 8.0	198	9.0	213	(K_W) 8.6	ΔP=350
SC Liquid Manifold	80	2.0	175	3.6	198	4.0	213	3.9	ΔP=100
SC Liquid Injector	80	2.0	175	3.6	198	4.0	213	3.9	ΔP=315

* Minimum area to keep ΔP at or below ARES ΔP. Where areas was not available, overall admittance factor K_W is shown,

where $K_W = \dfrac{\dot{W}}{\sqrt{\Delta P \times S.G.}}$ (K_W is directly proportional to area).

Module Flow Passage Dimensions (u)

Figure III-12

	Case 1 N_2O_4 A-50		Case 2 N_2O_4 A1-43		Case 3 98% H_2O_2 A1-43		Case 4 Comp A N_2H_4	
PUMPS FOR P.C. MAIN PROPELLANT	Propel-lant		Propel-lant		Propel-lant		Propel-lant	
Main Impeller Eye Dia. in.	Oxid	3.31	Oxid	3.16	Oxid	3.05	Fuel	3.21
Main Impeller Exit Dia. in.	Oxid	5.04	Oxid	4.96	Oxid	4.02	Fuel	5.37
Main Impeller Exit Port Width, in.	Oxid	0.36	Oxid	0.25	Oxid	0.356	Fuel	0.186
Boost Pump Impeller Dia. in.	Oxid	6.40	Oxid	4.95	Oxid	4.74	Fuel	5.09
PUMPS FOR P.C. SECOND PROPELLANT (Bipropellant primary only)								
Impeller Exit Dia in.	Fuel	3.67	Fuel	2.95		-		-
Impeller Port Width in.	Fuel	0.16	Fuel	0.11		-		-
PUMPS FOR S.C. LIQUID PROPELLANT INJECTION								
Main Impeller Eye Dia in.	Fuel	3.00	Fuel	3.50	Fuel	3.50	Oxid	3.59
Main Impeller Exit Dia in.	Fuel	4.70	Fuel	3.86	Fuel	3.86	Oxid	3.54
Main Impeller Exit Port Width, in.	Fuel	0.34	Fuel	0.60	Fuel	0.62	Oxid	0.52
Boost Pump Impeller Dia in.	Fuel	5.62	Fuel	6.33	Fuel	6.33	Oxid	5.72
TURBINE								
Turbine Tip Dia in.	Gas	6.00	Gas	5.30	Gas	5.79	Gas	6.31
Turbine Area $in.^2$	Gas	4.86	Gas	2.11	Gas	2.10	Gas	2.93
SECONDARY COMBUSTOR								
Throat Area $in.^2$	Gas	21.35	Gas	20.95	Gas	20.91	Gas	21.95
Throat Dia in.	Gas	5.21	Gas	5.16	Gas	5.16	Gas	5.29
Single Tube Area (Throat) $in.^2$	Oxid	0.034	Oxid		Oxid		Fuel	
VALVES								
P.C. Valve K_W***	Fuel	[illegible].92	Fuel	0.52	Oxid	6.90*	Fuel	7.00**
S.C. Valve K_W	Fuel	4.50	Fuel	8.00	Fuel	9.00	Oxid	8.60
Suction Valve Dia(P.C.feed end) in.	Oxid	3.35	Oxid	3.16	Oxid	3.05	Fuel	3.21
Suction Valve Dia(S.C.feed end) in.	Fuel	3.33	Fuel	3.50	Fuel	3.50	Oxid	3.59

\- -

*Oxidizer Monopropellant Valve

**Fuel Monopropellant Valve

***
$$K_W = \frac{\dot{W}}{\sqrt{\Delta P (S.G.)}}$$

Module Component Dimensions (u)

Figure III-13

	Case 2 N_2O_4 Al 43	Case 3 98% H_2O_2 Al 43	Case 4 Comp A N_2H_4
I. COMPONENTS			
Pumps For P.C. Main Propellant			
Main Impeller Eye Dia	A,1,a	A,1,a	A,1,a
Main Impeller Exit Dia	C,1,c	C,1,c	B,1,a or b
Main Impeller Port Width	C,1,c	C,1,c	B,1,b
Main Impeller inlet Housing Dia	A	A	A
Main Impeller Exit Housing Dia	A	A	B,2, a or f
Boost Pump	B,1,d	B,1,d	B,1,d
Pump for P.C. Second Propellant (bipropellant primary only)			
Impeller Exit Dia	C,1,c	D	D
Impeller Port Width	C,1,c	D	D
Pumps for S.C. Liquid Propellant Injection			
Main Impeller Eye Dia	B,1,b	B,1,b	B,1,b
Main Impeller Exit Dia			
Main Impeller Port Width			
Main Impeller Inlet Housing Dia			
Main Impeller Exit Housing Dia	B,1,b	B,1,b	B,1,b
Main Impeller Exit Housing Port Width			
Boost Pump	B,1,e	B,1,e	B,1,e
Turbine			
Tip Dia	A	A	A
Nozzle Throat-Blade Area	B,1,b	B,1,b	B,1,b
Housing Dia	A	A	A
Secondary Combustors			
Throat Dia	A	A	A
Tube Area	E,1,b	E,1,b	E,1,b

Coding Nomenclature

Dimensions	Timing	Action
A. Adequate	1. Incorporate or change at time of conversion	a. Satisfactory for off design operation.
B. Inadequate	2. Incorporate or change into present ARES design.	b. Resize part
C. Adequate to rework		c. Rework ARES part
D. Not Required		d. Substitute ARES fuel
E. Not Defined		e. Substitute ARES oxidizer
		f. Design to accommodate

Module Dimension Changes

Figure III-14, Sheet 1 of 2

	Case 2 N_2O_4 Al 43	Case 3 98% H_2O_2 Al 43	Case 4 Comp A N_2H_4
Valves			
P.C. Valve (bipropellant)	A,1,a	D	D
P.C. Valve (monopropellant)	D	E,1,b	E,1,b
S.C. Valve	B,1,b	B,1,b	B,1,b
Suction Valve Dia (P.C. feed end)	A,1,a	A,1,a	A,1,a
Suction Valve Dia (S.C. feed end)	A,1,a	A,1,a	A,1,a
II. FLOW PASSAGES			
Circuit for P.C. Main Propellant			
Suction Line	A or A, 1,d	A or A, 1,d	A or A, 1,d
Main Housing and Manifold	A	A	A
Manifold to P.C.	A	A	A
P.C. Injector	B,1,b	D	D
P.C. Catalyst Bed	D	E,1,b	E,1,b
P.C. Gas Passages	A	A	A
Circuit for P.C. Second Propellant (bipropellant only)			
Second stage Pump Volute Area	A	D	D
Passage to P.C. Control Valve	A	D	D
P.C. Manifold	A	D	D
P.C. Injector	B,1,b	D	D
Circuit for S.C. Liquid Propellant Injection			
Suction Line	B,1,e	B,1,e	B,1,e
Main Pump Volute	B,1,b	B,1,b	B,1,b
Line to S.C. Control Valve	B,1,b	B,1,b	B,1,b
S.C. Manifold	B,1,b	B,1,b	B,1,b
S.C. Injector	B,1,b	B,1,b	B,1,b

Module Dimension Changes

Figure III-14, Sheet 2 of 2

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